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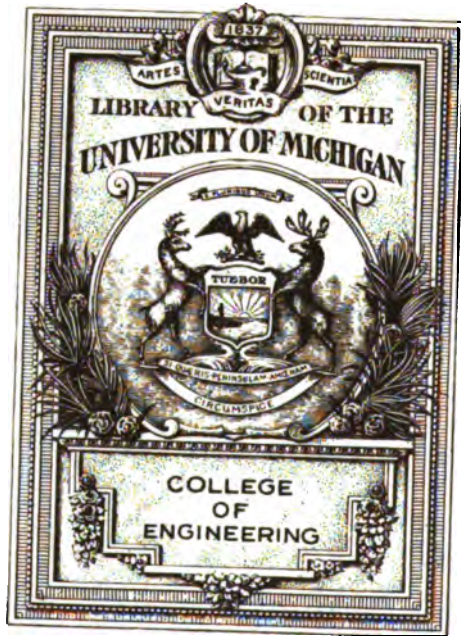
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WIRELESS TELEGRAPHY

WITH SPECIAL REFERENCE TO THE
QUENCHED-SPARK SYSTEM

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A Quenched-Spark land station, erected by Messrs. Siemens Bros. Ltd., at Cardiff.
[*Optispiece.*] [See p. 277.]

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WIRELESS TELEGRAPHY

WITH
SPECIAL REFERENCE TO THE
QUENCHED-SPARK SYSTEM

BY
BERNARD ^{John} LEGGETT, A.M.I.E.E.

*Late Wireless Technical Staff,
Messrs. Siemens Bros. and Co., Ltd.
Late Officer in Charge of Trench Wireless,
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EDITORIAL NOTE

THE DIRECTLY-USEFUL TECHNICAL SERIES requires a few words by way of introduction. Technical books of the past have arranged themselves largely under two sections: the Theoretical and the Practical. Theoretical books have been written more for the training of college students than for the supply of information to men in practice, and have been greatly filled with descriptions of an academic character. Practical books have often sought the other extreme, omitting the scientific basis upon which all good practice is built, whether discernible or not. The present series is intended to occupy a midway position. The information, the investigations, and the discussions are to be of a directly-useful character, but must at the same time be wedded to that proper amount of scientific explanation which alone will satisfy the inquiring mind. We shall thus appeal to all technical people throughout the land, either students or those in actual practice.

"Our national record in wireless telegraphy, apart from the financial side, is a sorry one. None of the new ideas that have revolutionised the subject during the past seven years can be regarded as having their origin or full development in this country. The conception of beat reception is American. The three electrode thermionic relay is American. The method of generating oscillations by aid of the thermionic relay was invented (probably independently) in Germany and the United States. The control of high-frequency currents by magnetic relays is likewise of German and American origin. The multiplication of frequency by aid of the properties of iron is French, Italian, and German. The success in high-frequency generators is American, French, and German. Even the design of valves which we used in tens of thousands in the War is not native; we have been the humble copyists of the French in this, and according to some accounts second rate in that capacity. The theory of the operation of the circuits is mainly due to French and Italian perspicacity. Nearly all amplifier design and development is French and American. Our main success in this subject during the War has been in the improvement in detail of wireless telegraph apparatus, and in this we may probably be credited with having done exceedingly well, but the fact remains that no novelties of the first order of importance arose in the work done in this country."—*Electrician*, Editorial, p. 228, 21st February, 1919.

AUTHOR'S PREFACE

IT is a matter for comment that whilst numerous works have been published, and others are still being produced, dealing with the highly important science of Wireless Telegraphy, yet none of these give more than a mere outline of the QUENCHED-SPARK SYSTEM, a system which has been employed in almost every country throughout the world. In view of its extensive adoption in such countries as the United States of America, Australia, Japan, China, and Germany, and considering that it can for land stations claim to rank with the Marconi System in importance, this lack of literature in England is difficult to understand. It is, however, probably the result of national prejudice, since the system had its origin in Germany, where it was experimented with and established by the Telefunken Co. The history and development are given in detail in the Introductory Chapter, and the efficiency of the Quenched-Spark Gap is so undoubted that its scientific merits cannot be ignored or dismissed by appeals to false patriotism. The original Telefunken System has been developed to such a large extent in other countries, including England, that the Quenched-Spark System, which is its outcome, can now be viewed as an International System.

The Author hopes and believes that the present book fills a distinct gap in wireless literature, as there is no volume at present in English which deals in detail with the Quenched-Spark System, either as manufactured in this or in other countries; or of the original Telefunken System. Much of the apparatus has never previously been illustrated and described in the English language, and much, including very many illustrations, has never yet been

published in any country. The Author is indebted to Messrs. Siemens Bros. & Co., Ltd., of Woolwich, for the majority of the photographs from which blocks have been made.

In the matter of block reproduction, at present a very expensive process, the Author wishes to give acknowledgment to the publishers, who have agreed with the writer that in technical descriptions a block is often of far more use than many pages of descriptive matter, and have, in consequence, spared no expense in the preparation of illustrations.

The Author has had considerable experience of actual manufacture, installation and operation of nearly all the apparatus described, and he hopes, therefore, that serious technical errors will not be found in the present volume. In this endeavour to avoid errors the Author has been fortunate in obtaining the assistance of several experts in the reading of the proofs. He wishes to render thanks to Mr. H. Machen, A.M.I.E.E., Chief of the Wireless Department, Messrs. Siemens Bros. & Co., Ltd., Woolwich, for his careful revision of proofs and for many suggestions of improvement, and also for much valuable assistance during his career.

The Author would particularly pay acknowledgment to Mr. J. L. Bale, of Messrs. Chapman & Hall, who has throughout given much assistance to the Author in rendering into book form what was previously a set of technical notes taken over a period of several years.

For further general proof reading, and particularly for suggestions and information regarding aeronautical wireless, the Author wishes to express his sincere thanks to Mr. S. T. G. Andrews, B.Sc. (Engineering). His gratitude is also due to Dr. L. Isserlis, B.A., Mathematical Tripos, and Mr. S. G. Starling, B.Sc., A.R.C.S., Examiner in Physics, London University, who have been kind enough to read the proofs of Chapter II., and offer suggestions.

The chapter on wireless propagation embodies an analogy which the Author has himself found very useful in interpreting wireless phenomena. Whilst not offered as an actual explana-

tion, possibly open to criticism, it should not detract from the more practical portions of the book.

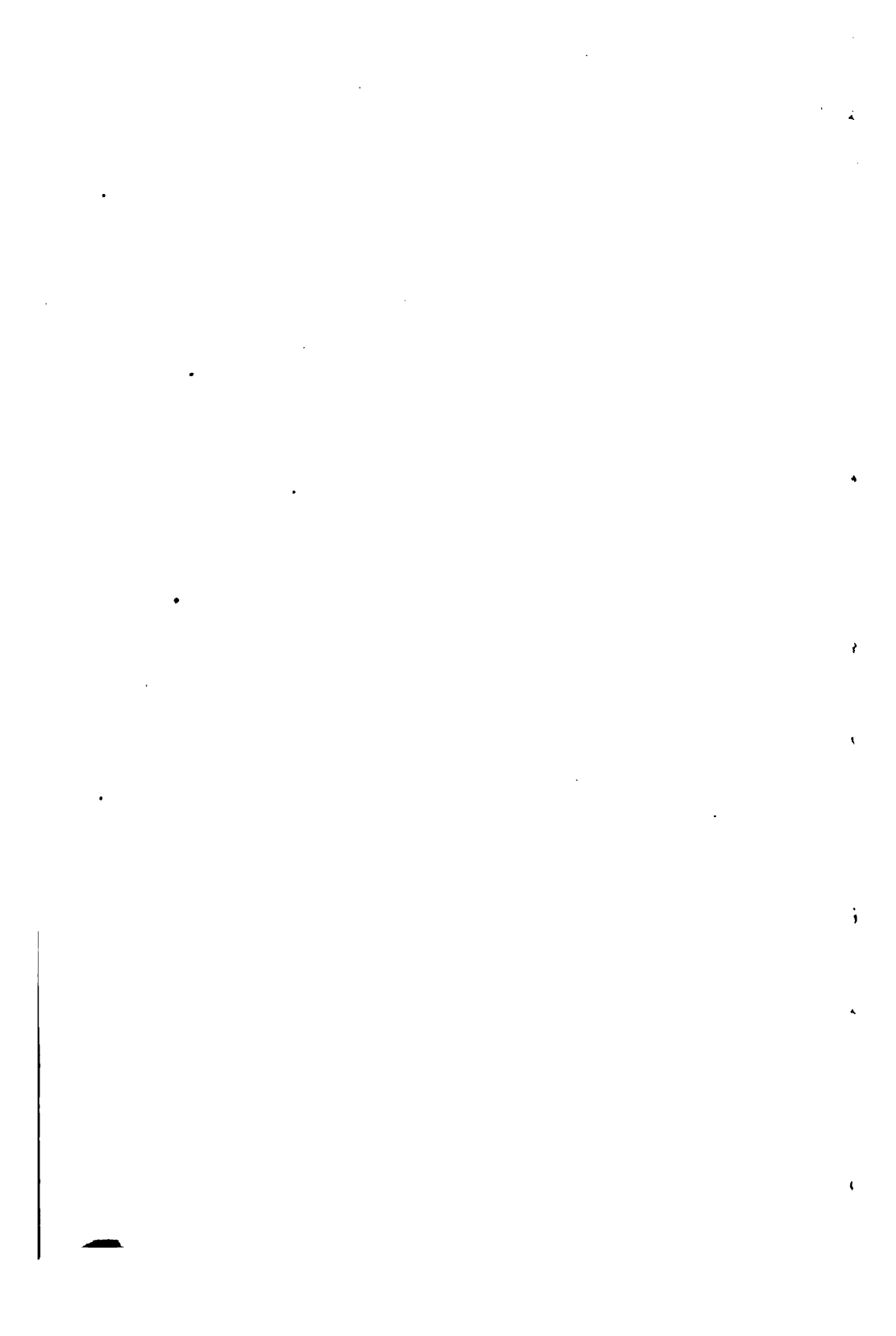
The chapter upon maintenance has been included in order to render the book of greater use to operators of the Quenched-Spark System, who are rapidly increasing in number now that a number of well-known shipping lines are fitting many of their new vessels with this system.

Acknowledgment is also due to the "English Mechanic" for permission to reproduce much of the matter of the earlier chapters, which the Author originally wrote for this Journal.

In conclusion, the Author would state that whilst in agreement with the spirit of the extract from the "Electrician" (given on p. vi), he does not himself believe the actual position to be as bad as this extract would imply, but the apparent general backwardness in English wireless may be partly attributed to the mistaken policy of Government Departments in withholding much scientific information obtained during the late War at great expense to the country. A particular example is afforded by the Signals Experimental Establishment Pamphlets which are available to those able to use the Library of the Institution of Electrical Engineers, and doubtless to many commercial firms having foreign connections, but which cannot be purchased by the general public who have borne the expense of their production. In this connection the Author believes Prof. Townsend of Oxford undertook for the military authorities extensive scientific researches showing comparisons between Open-, Quenched- and Rotary-Spark Gaps. No details of these tests of efficiency, which would undoubtedly be of great assistance to shipowners and others requiring to install new wireless apparatus, have yet been published.

BERNARD LEGGETT.

LONDON, *November, 1920.*



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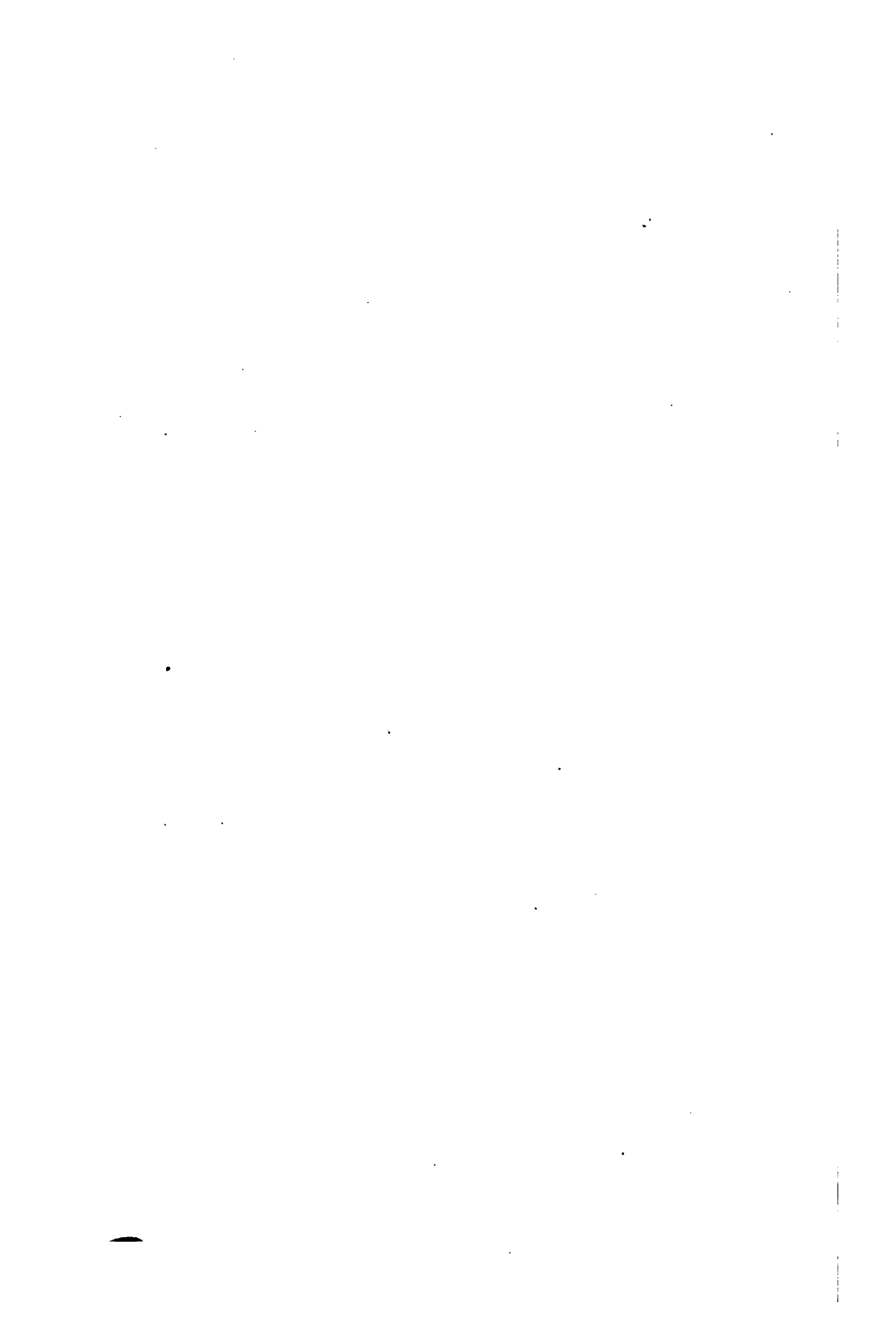
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INTRODUCTORY.

The International Character of the Progress of Wireless Telegraphy.—Contrary to much public belief in England, the “discovery” of wireless telegraphy is not in its entirety due to Mr. Marconi. For example, in 1894, two years before Mr. Marconi came to England, we find the Russian, Prof. Popoff, experimenting for purely scientific purposes with an apparatus for which he stated, “I may express the hope that my apparatus, with further improvements, may be adapted to the transmission of signals to a distance by the aid of quick electric sparks”. In the same year we find Sir Oliver Lodge before the Royal Society, using what was, in effect, the first wireless transmitter and receiver, even if it were only used for “signalling” purposes, and not specified as useful for “telegraphy”.

As with all scientific advances, wireless telegraphy is the sum total of the separate work of many investigators in all parts of the world, and its history may be said to extend back as far as 1838.

The salient points in the history of any field of scientific progress are largely a matter of personal opinion, but except in the matter of detail, the average unbiased historian will agree with the following notable advances towards the present-day position of wireless telegraphy:—

- 1838. K. A. Steinheil utilised the earth return in line telegraphy, and predicted the possibility of telegraphy without the use of even a single wire.
- 1840. Joseph Henry, in the United States, first produced high-frequency oscillations.
- 1853. Lord Kelvin enunciated the mathematical laws of uncoupled electrical oscillatory circuits.
- 1862. Joseph Heyworth, in England, patented a method of wireless conduction.
- 1867. The renowned English scientist, James Clerk Maxwell, read a paper before the Royal Society on the electromagnetic theory, and in 1873 predicted, on mathematical

- grounds, the existence of electro-magnetic radiations (already actually produced by Henry).
1879. Hughes discovered the coherer phenomena, later used by Branly for wireless detection. He also unwittingly discovered the existence of electro-magnetic radiations, but did not pursue the matter.
1883. C. F. Fitzgerald suggested the production of Maxwell's electrical oscillations by the discharge of a condenser, which is still the most important present-day method.
1886. A. E. Dolbear, of Boston, U.S.A., patented a wireless system, which utilised two insulated elevated plates, and this arrangement may be considered as an embryo aerial.
1887. H. R. Hertz, in Germany, carried out his now well-known classical experiments on Maxwell's prediction. He produced electrical waves and investigated the physical properties of refraction, etc., within the limits of his laboratory.
1889. Elihu Thompson suggested the use of electro-magnetic waves for signalling purposes.
1892. Edouard Branly, in France, devised his coherer for wireless wave detection, so rendering the detection more sensitive. This coherer was later for years used by Marconi and others, with small modification as to the composition of the coherent powder.
1894. Sir Oliver Lodge described his scientific experiments on electric waves before the Royal Society. Popoff's work, already mentioned, was also carried out about this period.
1895. Marconi commenced his experiments in Italy. He used the form of aerial devised by Popoff and Branly's coherer, both of which he later modified in detail. In 1896 he came to England, and his patents were acquired in 1897 by the Wireless Telegraph and Signal Company. For a detailed history of his early experiments, Fleming, or the Marconi publications, should be consulted.
1895. A. Overbeck's important mathematical paper on coupled oscillatory circuits appeared in the "Annalen der Physik," and was later, with the adoption of coupled circuits, to become of fundamental importance to practical wireless telegraphy.
1898. F. Braun, in Germany, introduced the present-day coupled circuits. The action is to give electric-magnetic waves of much sharper definition, so permitting of much more accurate tuning and avoidance of mutual interference

- or "jamming" between wireless stations. The Braun patent was of equal importance to the better-known "7777" patent. Marconi utilised these coupled circuits which resulted, in 1912, in mutual actions for infringement between the Telefunken and Marconi Companies, by which time the use of such circuits had for years been necessary and obligatory.
1906. Max Wien carried out a more elaborate investigation upon the nature of spark discharge in coupled circuits, introduced by Braun and Overbeck. He showed the importance of quenching the oscillations of one circuit, so permitting at least twice the radiation of energy from the aerial circuit and obtained practical results. This work was taken up by the Telefunken Company who evolved the present-day Quenched Gap, having double the efficiency of the older forms of spark gap.
1907. De Forest produced his "Audion" three electrode thermionic detector, but would appear not to have recognised the possibility of its use as an intensifier of received signals.
1911. Lieben and Reiss utilising a discovery, made by Wehnelt in 1904, that a conductor heated by electricity and coated with barium or calcium salts gave great electronic radiation, employed this in a three-electrode or Audion type of thermionic valve to produce not only a sensitive detector, but, much more important, an intensifying device. This immediately allowed the detection of far weaker signals than hitherto, and conversely, the range of existing stations was simultaneously greatly increased.
1913. Dr. Meissner, working for the Telefunken Company (which had acquired the Lieben and Reiss patent) discovered that such thermionic valve could not only be used to detect electrical waves, but also could be utilised to actually *generate* them for use in telegraphy and telephony transmission. Most modern short range telephony transmitters are now based on this discovery.
1914. Meissner, in Germany, and Langmuir, in the United States, and an investigator in the French Army, discovered independently, that gas was not necessary in thermionic valves. On the contrary, with a very high vacuum, the valve properties were more constant and therefore more useful, particularly when the valves were used as a source of high-frequency energy for transmitting purposes.

The above list of salient advances deals only with spark and valve telegraphy.

At the same period other investigators were experimenting on earth conduction methods, the most successful being Preece in England, and Kiebnitz in Germany, whilst Duddell in England, and later Poulsen in Sweden, elaborated the arc transmitter for wireless telephony and telegraphy. Goldschmidt in Germany, Alexanderson in the United States, Arco in Germany, and many others, were also developing high-frequency generators of various types for telephony work. Also in Japan three investigators were evolving with large success a practical system of wireless telephony which would appear to be based upon a reversal of the ordinary crystal detector phenomenon.

If we review all the above facts we see that those advances calling for the greatest scientific training and initiative were undoubtedly those of Maxwell, Hertz, and Wien.

Much credit must, however, be paid to Marconi, for making what had before been a scientific experiment, a practical method of telegraphy if only (at this date) for a few miles range. The future development of wireless telegraphy was afterwards the result of many investigators' work.

To the Marconi Company in England, and the Telefunken Company in Germany, must be paid the credit of utilising and rendering commercially practicable, the advances in wireless work made by various investigators. De Forest was simultaneously developing a system of wireless telegraphy, but his results have been more interesting than financial, and the progress in wireless telegraphy due to this investigator is unfortunately far from well known.

The Growth of International Control over Wireless Telegraphy Communication.—We have in the last section seen that wireless telegraphy was due to the labours of very many investigators in very many lands.

Naturally in such circumstances, upon the extended employment of wireless telegraphy, chiefly aboard ships, much confusion and unnecessary curtailment of its uses arose, when it was attempted to establish a commercial monopoly, not so much by technical superiority of apparatus, as by not permitting the operators of such stations to communicate with ships fitted by other systems.

This was the state of affairs previous to 1903, when the First International Congress on Wireless Telegraphy was held, the results of which were on economical grounds perhaps more important than many individual scientific and technical improvements.

Before 1903 the position was unsatisfactory, since shipping companies had no freedom of choice on technical grounds of the particular system of wireless telegraphy they wished to instal. The position arose by which, not only were ships of the same nationality forbidden to intercommunicate by a commercial company's orders, but even ships of the same shipping company were, owing to such orders, unable to communicate with each other.

Whilst such orders were perhaps permissible on commercial grounds, they were against the fullest utilisation of wireless telegraphy and tended against humanity.

Since 1892 in Germany, the installation of wireless apparatus had been the prerogative of the State, who could, in granting a licence, bind the installation down to work with any other particular stations it desired. In spite of this the situation before 1903 was, on international grounds, so unsatisfactory, that the German Government, in 1903, tendered invitations to all important nations to attend an International Congress on Radiotelegraphy in Berlin. This invitation was accepted by eight Governments, namely, Great Britain, Germany, France, Russia, Italy, Austria-Hungary, the United States of America, and Spain.

The editor of the "Electrician" in his issue of 4th September, 1903, commented upon the objects of this forthcoming conference as follows:—

"The question at issue is whether steps should be taken to prevent a single company from enjoying the monopoly of wireless telegraphy communication with ships at sea. . . . If Great Britain still refuses to fall in with the views of the other Great Powers in this respect it will be committing a grave indiscretion."

The main outcome of this Conference was that most of the Governments agreed to make it compulsory for their nation's coast stations to communicate with ships at sea, irrespective of their nationality and the particular system of wireless telegraphy installed.

The "Electrician" of 20th November, 1903, after the conference stated: "The position of reserve taken up by the British delegates to the Conference is regrettable, but nevertheless it could not be avoided in view of the present condition of the law of the land".

This position of reserve was due to there not being in Great Britain, unlike other civilised countries, law by which the Government could impose its will upon private commercial wireless companies. This position was immediately rectified by the passage of the "Wireless Telegraphy Act" of 1904, which

gave a monopoly of wireless telegraphy installation to the Postmaster-General, who, in granting a licence to instal and work a wireless station, could impose any necessary conditions, such as obligations to work with other systems of wireless telegraphy.

There were two dissentient nations to this obligation to work between shore and ship irrespective of system, namely, the United States of America and Italy. All the remaining nations simultaneously agreed to make communication between ship and ship similarly obligatory without regard to the particular system, with the exception of Great Britain, which had, outside of territorial waters, no legal powers upon its ships' wireless installations in this respect.

Italy recognised the necessity of the above regulation regarding ship and shore traffic but was unable to agree to it, since, under a previous contract for the installation of its coast stations, it had agreed, that such stations should only communicate with vessels installed with the same system of wireless telegraphy.

In this respect Italy suffered under great commercial disadvantage. Whilst its coast stations were unable to communicate with the large number of vessels not installed with the same system, these vessels were under no similar disability, since when in Italian territorial waters, they could easily communicate with the French or Austrian coast stations which had agreed to the Convention. By this means a very great proportion of the possible revenue of such Italian stations was lost to Italy, which had to maintain coast installations solely for the ships fitted by a single company.

The U.S.A. had at first been in agreement with the resolution but later withdrew in favour of giving the particular stations discretion to intercommunicate if they so desired.

In 1906 a Second International Conference was held in Berlin in which the number of nations attending had increased to twenty-nine. The most important resolutions were to establish methods for the collection of charges for radio-telegrams and the publication of necessary information for this purpose. In order to carry out this work the International Radio-telegraphic Bureau was established at Berne, in Switzerland, the expenses being borne by the various contributory Governments. Such an International Bureau had been long established for dealing with ordinary international land-line charges, and the "Electrician" commenting upon this Conference in its issue of 9th November, 1906, stated :—

"The whole question is one between private enterprise and

international policy. Inasmuch as the Marconi Company is a British concern we should like this company to have as free a field, as possible, but when it comes to a case of international communication it is surely impossible to expect any station should be privileged to refuse messages from any other simply because they are transmitted by some rival system. In telegraphy with wires no such proposition would be entertained for a moment, why then should it be for wireless telegraphy?"

The President of the Second International Radio-telegraphic Conference at Berlin in 1906 was the British Postmaster-General, Sir Henry Babington Smith, who on his return to England reported to the Select Committee of the House of Commons as follows:—

"The main object of the Marconi Company, in endeavouring to make the supply of their apparatus conditional upon its not being used for communication with stations equipped with other systems, has been to secure a monopoly by forcing all ships to use this particular system in order to communicate with the British coast. There are objections to such a monopoly from the point of view of public interest."¹

In America the withholdance of the U.S.A. from the convention had been largely overcome by the installation of new coast stations by companies willing to intercommunicate with all ships. The chief stations were those of the American Government itself and the large Telefunken station at Sayville, near New York.

On 1st July, 1911, a very important law regarding wireless telegraphy came into force in the United States, whereby all ships entering U.S.A. harbours, irrespective of their nationality, were bound to intercommunicate with all other systems of wireless telegraphy on ships, under penalty of very heavy monetary penalties, on their again entering a U.S.A. port.

As this also applied to all British and Italian ships which entered American ports, on the passage of this law, a position was obtained whereby the very great majority of ships fitted with wireless telegraphy were, irrespective of the wireless companies' orders, bound to communicate with each other, a position similar to the ship to-ship regulation affecting all other countries agreeing to the 1903 Conference informal resolutions to this effect.

The only nation to suffer was Great Britain in respect of those ships fitted by more modern systems. Such ship stations could work with all land stations and all foreign ship stations except

¹ "Electrician," p. 902, 22nd March, 1907.

those of Great Britain and Italy, not entering American ports. Whilst the ships so affected were small in number, for work between British ships this was a serious disability.

In 1912 a Third International Conference was held in London and every nation in the world attended and agreed to its resolutions, excepting Argentina, which, however, shortly after notified its agreement. This Conference made it obligatory for all ships' stations to communicate with each other irrespective of the system of wireless telegraphy used, and such is the present-day position.

Other important resolutions at this Conference made it necessary for ship stations carrying wireless apparatus to be regulated by their respective Governments to certain classes, such classification depending upon the tonnage or passengers carried.

The effect of this regulation was to make wireless apparatus compulsory on most mercantile ships, the necessary internal laws being shortly after passed by the respective Governments.

This Conference, which met shortly after the "Titanic" disaster, made regulations necessitating the employment of at least two operators on board those ships stated to have a continuous watch. This was a very necessary regulation since at the "Titanic" inquiry it was shown that the loss of life might have been entirely avoided had ships which were stated to have such a continuous watch been listening for distress calls, whereas the actual facts were that many British ships, including one within eighteen miles of the "Titanic," carried only one operator to provide such a continuous watch, which under such circumstances was naturally a physical impossibility.

The absence of an emergency installation on the recently installed "Titanic" was also a regrettable factor of the disaster (in which respect other countries' ship installations were better provided for, previous to this resolution being passed). At the Conference the installation of an emergency battery and transmitter was made compulsory for most vessels.

The Relative Importance of the Quenched-Spark System. Whilst at the present day a very large number of books dealing with wireless telegraphy are published, yet with very few exceptions these are not written by actual wireless engineers.

This leads to two types of book, either those written by the pure scientist, which are highly mathematical, and whilst of great theoretical interest are relatively unimportant in practical work; or to a more popular class of book which deals with actual wireless apparatus, but whose matter is largely obtained second-hand from other books, such as the admirable treatise by

Fleming, which chiefly deals with the Marconi system; the excellent practical handbook on the same system by Hawkhead; or the smaller, but perhaps more general and useful book by Eccles.

In Fleming's treatise the achievements of Mr. Marconi and the apparatus of the Marconi Company are dealt with at great length, but it is a matter for comment that the apparatus of this company's greatest competitor, namely, the Telefunken and Quenched-Spark system, receives very scanty notice, and indeed its name does not appear in the index to his book.

Eccles' book is far more general in nature, but as the book is much more restricted in size, his matter on the Telefunken and Quenched-Spark systems is necessarily small.

The sources of information regarding the original Telefunken system are very restricted, especially to those unable to read German. Such restriction of information is purely insular. The average English reader is practically unaware of the existence of any important commercial system of wireless telegraphy other than that of the Marconi Company, and is quite astounded when told of the existence of another system which, outside England and a few of its Colonies, is perhaps for land stations the most extensively adopted by other countries.

Since the original home of the Quenched-Spark system is Germany, national prejudice has, until recently, prevented the full recognition of this important system of wireless telegraphy, in spite of its great scientific merits.

There is, however, only one test of any scientific apparatus, namely, its efficiency. Since the Quenched-Spark Gap has at least twice the efficiency of any other form of spark gap, it is far from patriotic to neglect the possibilities of this system. On the contrary, it is a truer form of patriotism to examine, impartially and scientifically, the merits and demerits of foreign scientific work, German or otherwise, and then to utilise the results of such examination to the furtherance of British science and technology.

The importance of the regulation of international wireless telegraphy had, in the year 1903, as already mentioned, become so great that it became the subject of periodic International Conferences between the delegates of every civilised nation. One result of such Conferences was to establish an "International Bureau for Radio-telegraphy" at Berne, for the maintenance of which practically every country of importance (including Great Britain and its Colonies) contributes.

LAND STATIONS.
COMPILED FROM THE INTERNATIONAL LIST OF RADIO-TELEGRAPHIC STATIONS UP TO JUNE, 1913 (INCLUDING SUPPLEMENT I).

System.	Telefunken.	Marconi.	Société Française Radio-Électrique.	French State.	Australian Commonwealth.	Lorenz.	Compagnie Générale Radio-télégraphique.	Shoemaker.	Rochefort.	Lodge-Muirhead.	De Forest.	Poulsen.	Lepl.	Teishinsho.	Branly-Popp.	U.S.A. Government.	Wireless Specialty Co.	Unnamed.	Cost of Transmission per Word (Centimes).
Alaska	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	25, 30
Argentina	19	—	—	—	—	—	—	—	—	—	—	—	—	—	—	17	—	—	—
Australia	—	—	—	—	7	—	—	—	—	—	—	—	—	—	—	—	—	—	60, 30
Austria-Hungary	4	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	30, 60
Belgium	—	1	9	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	20
Belgium Congo	3	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	50
Brazil	7	4	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	60
British Guinea	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	60
British India	—	3	—	—	—	—	—	—	—	8	—	—	—	—	—	—	—	—	60
British Somaliland	—	2	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	35
British South Africa	—	2	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	60
Bulgaria	—	1	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	30
Canada	—	34	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	60, 85
Caroline Islands	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	60
Ceylon	—	1	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	35
Chile	—	1	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
China	—	3	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	25
Cocos Keeling Island	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	60
Cuba	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Curacao	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	30
Denmark	3	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	60
Dutch East Indies	—	7	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	15
Egypt	—	3	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	40
England	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	60
Falkland Islands	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	60
Fiji Islands	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	60
France	—	3	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	40
French Equatorial Africa	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	30
French West Africa	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	30
German Cameroons	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	35
German China	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	18

¹ The only important non-contributory Government in 1913, but shortly after contributory, and therefore inserted from a later list.

INTRODUCTORY

LAND STATIONS (continued).

German East Africa	1																						35
German S. W. Africa	2																						35
Germany	17																						18
Gibraltar																						2	60
Gold Coast																							50, 30
Greece																						1	20
Hawaiian Islands																						1	50
Holland																						5	30
Hong Kong																						3	30
Indo-China					3																		60
Italy																							
Italian Somaliland																							
Japan																							
Liberia					1																		50
Madagascar					1																		30
Malta																							25
Marian Islands																							30
Mexico																							25
Morocco										2													26, 57
New Zealand																							14, 20
Norway																							60
Palao Islands																							30
Panama																							
Philippines																							13
Portugal											5												4
Rumania																							60
Russia																							45
Spain																							
Spanish Guinea																							
Spanish Morocco																							
Sweden																							14
Tunis																							40
United States																							18
Uruguay																							15, 30, 60
West Indies												2											53
Zanzibar													2										60
	129	138	11	30	7	1	2	1	6	15	7	3	1	7	1	59	1	82					

One of the duties of this Bureau is to compile, from information supplied by the official telegraphic departments of the contributory nations, an "International List of Radio-telegraphic Stations".

If, therefore, we wish to compare the relative importance of various systems of wireless telegraphy, there is no better way of doing so, than by reference to this list, since it is purely official and no commercial company can in any way determine its compilation.

In making such a comparison of different systems of wireless telegraphy, the author purposely uses the list of 1913, i.e. the last issued before the war. The reason for doing so is that the current list is not so reliable, since the various combatant Governments during the war did not, for obvious reasons, contribute any information likely to be of value to their enemies. Hence in the current list we still find British and other ship stations given, although such ships were sunk quite early in the war, ship stations on German ships taken over by the Allies still given as German, stations in the various German Colonies occupied by our forces and those of our Allies still given as German, and land stations, such as those in British North Borneo, which have been working commercially for some years during the late war, not yet given in the list. A new list is, however, about to be issued but is not at the time of writing available, and it is unlikely that it will differ relatively from the 1913 list.

Examining first a complete list of land stations, this gives the information on pp. 10 and 11.

We see from this list that if we wish to judge the relative importance of various systems of wireless telegraphy we can roughly do so, by dividing the total number by four, when one-fourth will represent those of the Marconi system, one-fourth those of the Telefunken system. The other two-fourths represent the total of all the various other systems, the most important in point of view of numbers being that of the United States Government, which is roughly half that of the two systems already mentioned.

It must, however, be borne in mind that many of these other systems employ Quenched-Spark Gaps little different to the original Telefunken Gap; for example, the Lepel system employs a spark gap whose chief difference is the replacement of the mica discs between the spark-gap plates by paper discs. Among other systems employing the Quenched Gap are the French State, the U.S.A. Navy, many of the composite U.S.A. Revenue Cutter Service stations, the American Marconi Company, the Anglo-American Company, the Japanese Teishinsho

system, and the Australian Commonwealth, Helsby, Huth, Willis-Boas systems. Hence we may safely say, that the majority of the world's wireless land stations employ the Telefunken Quenched Gap, either installed by that company, unmodified but not installed by this company, or very slightly modified.

As a guide to the relative working efficiency of each system, whilst analysing the list just given, it is interesting to notice the relative cost per word for transmission.

These will be found (for the usual type of vessel making a voyage over 500 miles) to be greatest in Britain and its Colonies, namely, 60 centimes per word, whereas it is only 40 centimes per word for France, 30 centimes for Italy, 20 centimes for Belgium, Holland, and Norway, 18 centimes for Germany, 15 centimes for Denmark, and 14 centimes for Sweden. Hence we see that whilst England was the first home of commercial wireless telegraphy, the relative cost of transmission is over four times as great as for Sweden, and over three times as great as for Germany, both of which countries employ the Telefunken system.

It should, however, be noted that though England and Italy employ exactly the same system of telegraphy, the cost of transmission in England is, for some reason, just double that in Italy. It is true that in England we have a complicated tariff of charges, based upon the distance of a vessel's voyage, but as this distance has no influence whatever upon the actual wireless transmission, the reason for the same is not evident. Since most ships using wireless apparatus voyage over 500 miles, the most usual charge is 60 centimes, as given on page 10.

Examining now a similar list of ships' stations we obtain the results given on the next page.

In this list the "Debeg" stations, which are manufactured by the Telefunken Company, are, for reasons given later, correctly given as such (see p. 24).

Whilst it will be seen that the largest number of ships' installations are those on the Marconi system, in estimating the relative importance of the Telefunken stations we must bear in mind—

(1) That England as compared to any other nation has a relatively much greater mercantile marine, and therefore offers much greater scope for any wireless company operating in England.

(2) The original Telefunken apparatus was not developed for ship work and did not enter upon such installation work until relatively late in wireless history.

As far as naval ship stations are concerned, with the exception of Britain and Italy, these are either manufactured by the

WIRELESS TELEGRAPHY

COMPILED FROM THE INTERNATIONAL LIST OF RADIO-TELEGRAPHIC STATIONS UP TO JUNE, 1913 (INCLUDING SUPPLEMENT I).
SHIP STATIONS.

System.	Telfunken	Debeg.	Marconi.	Société Française Radio-Électrique.	French State.	Australian Commonwealth.	Lorenz.	Compagnie Générale Radio-télégraphique.	Shoemaker.	Rocherfort.	Lodge-Muthead.	De Forest.	Poulsen.	Lepel.	Telshisho.	Brady-Popp.	U.S.A. Government.	Wireless Specialty Co.	Huh.	United Wireless.	Helby.	Anglo-American Telegraph Co.	Willis-Boas.	Resenden.	S.A.I.T.	Unnamed.	
Argentina	57		19																								
Australia																											
Austria	33		1																								
Austria-Hungary	55		16																								
Belgium			15																								
Brazil	7																										
British Indies			2																								
Canada	1		46						3																		
Chile			9																								
Denmark	5		4																								
Dutch Indies	1																										
Egypt			1																								
England	43		507								13																
France			55		164			28																			431
Germany	302																										133
Greece	9		15																								7
Holland	29		52																								3
Italy			159																								64
Japan															32												
Monaco																											
New Zealand	6		11																								
Norway	8		5																								21
Portugal			8																								
Rumania																											
Russia	8		58																								83
Spain	8		9																								
Sweden	6																										
Uruguay																											
U.S.A.	1		89														214										1
	579	1031	29	164				28	3		13	31	1	1	32	5	214		1	18	4	1	9	5	3	801	

2994

Telefunken Company (Germany, Holland, Russia, South American Latin Nations, etc.) or are modifications of this system. They are, however, not specified as such in the Berne List and therefore not given as such in the above figures.

Italy until recent years has used the Marconi system, but of late years the naval stations are not definitely specified as being of any particular system. The British stations are given in the Berne List as Marconi-British Navy. Whilst our Admiralty paid a large sum for the use of the Marconi patents, it is hardly correct to call these stations Marconi, since this company does not manufacture or instal the same, but on the contrary they are installed by Navy personnel, and have been so remodelled that they bear little relation to the original system, and utilise coupled circuits first introduced in wireless practice by Braun.

We may safely say that the majority of naval stations throughout the world employ either the original or modified Telefunken Gap.

The complete analysis for both land and ships' stations, of all systems, show their relative importance to be as given in the table on the next page.

Sufficient has been given to indicate the world-wide adoption of the Quenched-Spark system, and to show its importance even when compared with the Marconi system.

The comparative absence of information on the Quenched-Spark system is therefore to be deplored, and undoubtedly it has been neglected in English wireless literature of past years. Such a neglect, by withholding information of results obtained abroad from those who only read English, is detrimental to general wireless progress, and particularly so in England.

As an example of this neglect, in the standard English book on wireless telegraphy, namely, Fleming's "Principles of Electric Wave Telegraphy," we find that whilst the index alone contains nearly two columns devoted to the Marconi apparatus, the word "Telefunken" does not appear in his index. Similarly, in a smaller and more popular book¹ we find the Telefunken system receives the following notice towards the end of the book:—

"With regard to the Telefunken appliances for radio-telegraphy which are used for ship and coast stations in Germany and *other countries within its sphere of influence*, these are identical in principle with those employed in the Marconi system, *except in the details of the spark discharger* and in the nature of the particular wave detector used."

¹"The Wonders of Wireless Telegraphy" (Fleming), p. 261.

The italics are the present author's ; when one considers that the countries *within the German sphere of influence*, when this was written, included England, Australia, British North Borneo, British West Africa, New Zealand, Japan, Spain, the U.S.A., and all the South American Latin countries, and more recently Zanzibar and Egypt ; and further the *details* of the spark discharger embody the results of highly scientific researches, one can only say that the above extract is far from giving a correct representation. Figures given by Fleming himself, in his large treatise, show that these *details* permit of double the radiation of energy obtained by use of the open spark gap (see p. 58).

SUMMARY OF WIRELESS STATIONS, WITH REFERENCE
TO PARTICULAR SYSTEMS.

System.	Coast Stations.	Ship Stations.
Marconi	138	1081
Telefunken	129	579
U.S.A. Government	59	214
French Government	30	164
Société Française	11	29
Lodge-Muirhead	15	13
Australian Commonwealth	7	—
De Forest	7	3
Teishinsho	7	32
Rochefort	6	—
Poulsen	3	—
Compagnie Générale	2	28
Lorenz	1	—
Shoemaker	1	3
Lepel	1	1
Branly-Popp	1	5
Wireless Specialty	1	—
Huth	—	1
United Wireless	—	18
Helsby	—	4
Anglo-American Telegr. Co.	—	1
Willis-Boas	—	9
Fessenden	—	5
S.A.I.T.	—	3
Unnamed	82	801
	501	2994
Total No.	3495	

It is regrettable that in England it has become the custom to treat wireless telegraphy as a wonderful and mysterious subject, instead of merely a specialised branch of electrical engineering, obeying physical laws, and whose mysteries are negligible in comparison to the unsolved problems of other branches of natural science.

Whilst such a treatment is doubtless useful for mere advertising purposes, it hardly aids the dispassionate scientific consideration upon which all progress depends.

In this respect the author believes that a pamphlet entitled "Wireless Telegraphy upon Ships," written by him in 1911 whilst in Messrs. Siemens' employ, for this company, was the first example of wireless propaganda work, which instead of appealing to human credulity, gave a bald statement of the advantages of wireless telegraphy to the shipowner, a statement of results obtained, and plain technical statements of the apparatus manufactured.

As evidence that the only true test of any scientific apparatus depends upon actual results, the author might mention the following incident described by an English paper, "The China Coast Shipping Gazette," as long ago as 3rd November, 1911.

The English steamer "Brodmore" was in Hankow harbour in distress with a perishable cargo of meat. The skipper, owing to destruction of the land lines by insurgents, was unable to wire to Shanghai for a relief ship to save his cargo. He approached the British Consul, with a request that a British warship in harbour should be utilised to send a wireless message to Shanghai and was informed that the wireless range of this warship was insufficient for it to do so. Lying in the harbour was the German warship "Leipsig" fitted with Telefunken apparatus. As it was in permanent communication with the German warship "Nurnberg" in Shanghai, the captain of the "Leipsig" offered to assist the "Brodmore" skipper by sending his message, the cargo so being eventually salvaged.

The above-mentioned paper quoted upon the incident to the following effect: "The system upon which the English Navy depends shows itself in a very bad light, and the English ships are unable to bridge large distances, while the German warships fitted with the Telefunken system are in easy permanent direct communication between Hankow and Shanghai. The German warship 'Leipsig' in Hankow is, we hear, in permanent communication with the 'Nurnberg' in this harbour, and exchanges regular

communication between Nanking and Tsingtau, a distance of 260 miles, and under favourable conditions, between Hankow and Tsingtau, a distance of not less than 450 miles."

Whilst it must be mentioned that the growth of an independent wireless personnel had, of recent years, and fortunately before the outbreak of war, resulted in a great improvement in our naval wireless apparatus, it is to be regretted, that our naval wireless apparatus was ever permitted to be in such a condition that an English paper should make such a comment, a comment which was taken up and made much of by the Berlin press, whilst it passed unnoticed in England, instead of being taken up with a demand for better apparatus for our Navy's use.

Similar incidents, previous to the war, were making the superior claims of the Telefunken system known to the British shipowner, and we find many shipowners taking advantage of the Quenched-Spark system, which, whilst founded upon the original Telefunken system, had been greatly modified in accordance with English engineering practice. Hence we find well-known British shipping firms installing the Quenched-Spark system, and these include, Alfred Holt & Co., The Blue Star Line, The Glen Line, The Henderson Line, The Brocklebank Line, The Federal Steam Navigation Company, The Clan Line, and many others. More recently the Cunard and Nelson Lines have installed Quenched-Spark apparatus.

When such well-known shipping firms are rapidly taking up the newer Quenched-Spark installations, when other technical commercial companies, such as the Eastern Telegraph Company (able to correctly appreciate the technical advantages of telegraphic apparatus), decide to instal the Quenched-Spark system in their land stations, and when other technical cable companies, such as the owners of the cable ship "Dacia," do likewise, it is evident that the time has passed when, in considering the advantages of wireless apparatus, scientific merits can be ignored or dismissed by appeals to national prejudice.

On the contrary, we can better follow the example of our Allies, the Japanese, and be ready to consider any scientific improvement, whatever its origin, and if the result of investigation warrants, adopt such improvements to our own needs and if possible further improve upon them.

The Development of the Telefunken System.—Since the year 1890, as the result of the classical experiments of R. Hertz, very many German investigators had been attempting to utilise electro-magnetic waves for telegraphic purposes.

Foremost amongst these was Prof. Slaby, who visited Marconi's early experiments in 1897.

Other celebrated German mathematical physicists, such as Prof. Wien, Dr. Drude, and Dr. Overbeck, were devoting attention to the more theoretical aspects, whilst Prof. Braun and Dr. Eichorn were studying the more practical telegraphic applications. The importance of Braun's work upon wireless progress may be correctly estimated by stating that the international Nobel Prize for Physics in 1910 was shared equally between himself and Marconi. In 1911 Prof. Wien received the Nobel Prize for Physics.

The results of Braun's work, which includes the fundamental patent for all modern coupled circuits, did much to prevent undue mutual interference, which up to this time resulted by the general use of "open or Marconi" aerials. His patents were exploited by "Prof. Braun's drahtlose Telegraphie Gesellschaft" (Prof. Braun's Wireless Telegraphy Company) which was later amalgamated to Siemens & Halske. The discoveries of Slaby were acquired by the German A.E.G.

In 1903 these companies, after much mutual patent litigation, amalgamated to form the "Gesellschaft für drahtlose Telegraphie," each company having then had five years' experience in high-frequency technology. The apparatus of the A.E.G. Company at this date had been adopted by the German Navy, and a large number of stations installed. The Braun-Siemens' apparatus had been adopted by the German Army for transportable stations for military purposes.

At the time of amalgamation of these companies the types of stations employed were not many. The primary energy used by both companies was from $\frac{1}{2}$ to 1 kw., the spark frequency being from 50-150. The Braun-Siemens' station was the first transportable wireless station in the world. The station was built upon a military limber waggon and actuated by a petrol motor, a direct current dynamo, current from which was transformed by aid of a resonant induction coil with a Wehnelt interrupter. The transmitter consisted of Leyden jar condensers and an oil-immersed high-frequency transformer.

The receiver is worthy of notice. As a detector the coherer was used, with an auxiliary aural apparatus, consisting of a contact detector of polished steel and graphite. This receiver was also fitted with a variable condenser for tuning purposes which is scarcely missing in any present-day station.

The A.E.G. naval transmitter also employed direct current

and a mercury turbine interrupter, the excitation circuit having Leyden jar capacities. The receiver was coupled by self-inductance to the aerial, coherer detectors being used, with an auxiliary electrolytic detector.

Radio-telegraphy was so little advanced at this date that both companies' transmitters, in common with other wireless companies, used low-frequency measuring instruments.

Both companies had an early form of wavemeter, but the credit is due to the A.E.G. Company of producing the first wavemeter in the world, consisting of a variable self-inductance and a fixed condenser (Slaby rod), present-day practice being the reverse of this, i.e. a fixed inductance and variable condenser being now chiefly used. Resonance was shown by measurement of the voltage.

The latter was the type of wavemeter later evolved by the Braun-Siemens Company. This was of the Franke-Donetz type and consisted of a variable resonating circuit, tuning being carried out by means of a variable oil-condenser, and resonance being shown by hot wire instruments. With the inception of this instrument it first became possible to carry out measurements of damping of circuits.

After the foundation of the Telefunken Company, a large amount of technical work was necessary for the amalgamation of the apparatus of both companies and for the preparation of an aural receiver to replace the more insensitive coherer detector. Very soon difficult technical tasks were encountered by the new company, the solutions of which led to improvements in coupling, etc., and to the construction of more powerful apparatus.¹ To be specially noted is the erection of the Norddeich Coast Station, which was carried out by the Telefunken Company in 1906 for the German Post Office. At this station a transmitter was built, which utilised 20 kw. of alternating energy for 50 sparks per second. Between the normal model and this (at this date) large transmitter, many intermediate types were soon evolved. As the energy sent out was received by a number of very simple wireless stations, the sensitiveness of the coherer apparatus to "atmospherics" was soon per-

¹ For detailed descriptions of this early apparatus, Eichorn's "Wireless Telegraphy" (Griffin & Co.), or Zenneck's "Wireless Telegraphy" (MacGraw Hill), should be consulted in the English language, or Zenneck's "Electromagnetische Schwingungen" (F. Enke, Stuttgart), or A. Prasch's "Fortschritte auf dem Gebiete der Drahtlosen Telegraphie," 1900-1906 (4 vols.), (F. Enke, Stuttgart), in the German language.

ceived. To overcome this, loose coupling of the receiver was introduced for the first time by Dr. Eichorn of the Braun-Siemens Company at the Experimental Station at Saltznitz-Trelleborg. At the same time the coherer was replaced by aural apparatus, first by electrolytical detectors and later by crystal detectors. The spark frequency was also increased, and, as is now known, this had the effect of permitting the transmitter to radiate more energy without increasing the size of the aerial, although a limit to such increase was soon reached, since the old open form of gap was still in use, with which increase of frequency of discharge leads to arcing and not to a true spark discharge.

Within the first year of amalgamation the Telefunken Company erected 163 stations, and in 1904 erected 191 stations.

In 1903, at the instance of the German Government, the first International Congress on Radio-telegraphy was held in Berlin, and was attended by delegates from Great Britain, Germany, France, U.S.A., Italy, Austria-Hungary, Spain, and Russia. The result of this Conference, was to establish the first international wireless regulations, to partially destroy the very serious and injurious monopoly which had arisen in maritime work, and to make the control of wireless working the prerogative of the various States and not that of particular companies. Traffic between ship and shore was made compulsory to all stations irrespective of the particular system of wireless used, and this assisted the extension of the Telefunken system outside of Germany.

In 1904 the Russo-Japanese War was ensuing, and many military stations were supplied to the Russian Army. Owing to these being operated by unskilled Russian personnel they gave at first bad results, which were, however, later improved by the training of technical personnel. Better immediate results were obtained with installations supplied in this year for the use of the German forces in the German Herero-Campaign in South-West Africa, owing to their operation by skilled personnel. Wireless stations were also supplied to the navies of the U.S.A., Germany, Austria, Sweden, Denmark, Norway, and Spain, and were used by the Turks in the Italian Tripoli Campaign.

The years 1906-7 mark an epoch in general wireless history owing to Poulsen's discovery of the generation of continuous wave oscillations by means of the electric arc in an hydrogen atmosphere. It has not, as was then believed, replaced the spark system, but on the other hand, a great deal of improvement of the spark transmitter was caused by competition

due to the introduction of a number of continuous arc-lamp stations.

During this period of development the Telefunken Company thoroughly investigated the arc-lamp method, and in this respect produced a prior record, in so far that in December, 1908, in the presence of the Under-Secretary of State, Lydow, and Prof. Slaby, wireless telephony had been carried out between their laboratory in Berlin and their experimental station at Nauen, a distance of 35 km. By these experiments, conditions were found by which it is possible to generate undamped waves by shock excitation by means of arc lamps. With such transmitters, however, it was found impossible to obtain a steady alternating current supply during transmission, and this question was not further pursued by the company.

The hot-wire ammeter of the transmitting aerial, was now introduced for control of the radiation, and by this means a large number of unforeseen questions of wireless were investigated. By further increase in the spark frequency, the energy in the aerial was still further increased.

In 1906 the discovery was made by Prof. Wien of shock-excitation as a means of quenching the oscillations in the excitation circuit. The Telefunken Company investigated the question of shock-excitation with all possible forms of spark gaps, including mercury-vapour lamps and vacuum spark gaps. In this way the spark frequency was increased to more than 1000 per second. After about two years of intense laboratory work, the first quench-spark station upon the Telefunken system was produced, which worked with 1 kw. in the aerial, and was installed for testing purposes upon a commercial ship. One can imagine the amazement and astonishment which was created when the signal of the first musical transmitter was heard.

The next improvement was the use of a series of spark gaps which could be cooled and be used in combination with a correctly determined coupling between the excitation circuit and aerial. *This was the new principle upon which the Telefunken Company constructed the first Quenched-Spark transmitter in the world.* The high-spark frequency used permitted, for any given energy, a decrease in the voltage of the aerial so that the self-induction coils would be made smaller. A special form of variometer was also produced, and by means of this it was possible to produce the first Quenched-Spark station with a continuous wave range.

Further developments led to the attainment of larger wave

range and the extension of the use of wireless telegraphy in very many lands, including the tropics. The number of words which could be transmitted per minute was increased, and transmission over a longer interval of time during the day was obtained. This led to new observations and changes of construction. While in the beginning of the use of the Quenched-Spark, only a few standard types were manufactured, requiring primary energy ranging from 1 to 10 kw., the number of types manufactured became more and more, the smallest type which is manufactured to-day requiring about 200 watts primary energy. Much more powerful stations were manufactured, the most powerful type being built as an experimental station at Nauen and tested there. Soon a type requiring 50 to 60 kw. of primary energy was evolved. This station could communicate with ships at a distance of 3000 km. At the end of the year a type was evolved which required 200 to 300 kw. and which radiated more than 100 kw. from the aerial. This latter type of large Telefunken station obtained with ships a range up to 5000 km. It also communicated with Togo at a distance of 5200 km., and then with America at a distance of 6400 km.

With these larger types of station, it was possible to raise the speed of transmission up to 50 words per minute.

Other technical improvements, such as the equipment of stations with apparatus so that messages could be received during the intervals between the Morse signals during transmission (Duplex-Relay), and apparatus which enabled two messages to be received from the same aerial at the same time (Double Receiving Switch), were produced during this period of development.

Throughout this period of development already dealt with, namely, from the inception of the Telefunken Company up to 1912, there had been a very bitter controversy between this company and the Marconi Company, and actions for infringement of patents had been commenced by both companies throughout the world, particularly in England, Australia, and the U.S.A.

It is not the purpose of this book to take sides in any such commercial controversy. Those who are interested in such a commercial dispute are referred to Bredow's article in the "Jahrbuch der Schiffbautechnischen Gesellschaft" (Year Book of the Institute of Shipbuilders) for 1912, an article which should certainly be read by those compiling any historical account of wireless telegraphy. This article is one of those recommended by the Marconi Year Book, but the original article should

certainly be read, since although it was translated into English shortly after the Telefunken-Marconi agreement, the most interesting portion of the article dealing with the commercial aspects was then omitted.

In 1910, at the request and in the interests of German shipowners, particularly the Hamburg-America and the North German Lloyd Lines, an arrangement was entered into between the Telefunken Company and the Belgium Marconi Company, which resulted in the formation of an operating company, the "Debeg" Deutsche Betriebsgesellschaft für drahtlose Telegraphie. The foundation of this company was largely owing to the difficulties experienced by the shipowners, by their having to deal with two rival wireless companies, the Telefunken Company for the more recently installed stations, and the Marconi Company for previously installed stations, for which the existing contracts had not expired. Whilst by Germany's acceptance of the informal resolutions of the 1903 Conference, relating to ship-to-ship traffic, such stations were compelled to intercommunicate, great friction was still experienced to the shipowners' disadvantage.

The new company purchased all previously installed ships' stations and operated the same. As the Telefunken Company had the controlling interests, and at the request of the shipowners, as soon as pre-existing contracts expired, the newer Telefunken apparatus was installed. At the present day the author does not know of a single German ship, operated by the Debeg, carrying other than Telefunken stations.

For this reason on page 14 the Debeg stations were correctly included with the Telefunken stations, an inclusion also made by the latter company itself.

By 1911 the Telefunken system had been employed in almost every country throughout the world, and of particular interest is the fact that in June, 1912, permanent wireless communication was established by the Australian Telefunken licensees across Australia between Perth and Fremantle. Litigation between the Australian Commonwealth Government and the Marconi Company regarding these stations occurred, the final result being that the Marconi Company withdrew their action upon the payment of the comparatively small sum of £5000, whilst giving to the Australian Commonwealth the right to use their patents. The Telefunken system was also adopted by the New Zealand Government for land stations, and Sir Joseph Ward strongly defended the Government contract in the New

Zealand Parliament on the grounds of greatest efficiency and economy.

In 1912 an arrangement was made between the Telefunken Company and the Marconi Company, whereby each company agreed to drop their mutual patent litigation throughout the world and exchange past and future patent rights. This arrangement was doubtless more commercially economical to both companies, but possibly also largely removed the previous healthy competition. The effect of such exchange of patent rights after this date is to be seen in the patent specifications of the two companies, for example, soon after the Telefunken-Marconi agreement we find Franklin, of the Marconi Company, taking out British patent rights for a thermionic intensifier, similar in fundamental principle to the Lieben valve of the Telefunken Company. Similarly in 1913, Meissner, of the Telefunken Company, using the thermionic valve for reception purposes, made the important discovery that continuous waves could be also generated by thermionic valves, and in 1914 we find a patent on the same subject by Round, of the Marconi Company in England.

The growth of types manufactured by the Telefunken Company between the period of 1903 and 1913 can be seen from the following tables which gives the normal types manufactured during 1903 and 1913 :—

TYPES OF STATIONS MANUFACTURED IN 1903.

1. Range up to 25 km.
1 mast 20 to 35 metres in height, primary energy 350 watts (60 to 120 cells).
2. Ditto up to 50 km.
1 mast 30 m. high or 2-20 m. high, primary energy 16 cells = 32 volts.
3. Ditto 100 to 200 km.
1 mast 50 m. high or 2-35 m. high, primary energy 2 h.p. and accumulators 64 volts 17 amps.
4. Ditto 350 km.
1 mast 60 m. high or 2-40 m. high, primary energy 4 h.p.
5. Portable Station (100 km.).
2-4 horse wagons, primary energy 4 h.p. (2.5 kw.), balloon cable antenna, 200 m. long.

The nomenclature adopted for these various types of station is based upon the energy radiated from the aerial which is the most rational way, since the prime energy gives no guide to the possible range, when the ratio of energy transmitted to prime energy radiated may vary from 10-25 per cent. for the open-spark transmitter to 50-75 per cent. for the Quenched-Spark transmitter.

The figures denote energy radiated in kilowatts. K denotes a station having fixed wavelengths; V, a station with a continuously variable wave range; L, a station with Leyden jar capacity; B, P, Ae, M, F, and A, balloon, pack set, aeroplane, airship, limber waggon, and motor car installations respectively.

WIRELESS TELEGRAPHY

TYPES OF STATIONS MANUFACTURED IN 1913.

Type of Station.		Primary Energy (kilowatts).	Normal Wavelengths (metres).	Normal Range (kilometres).	
				Sea (10 per cent. Land).	Flat Land.
				Day. Night.	Day. Night.
LAND STATIONS.					
1	0.1 LK School Station	0.2	300, 450	110	180
2	0.2 TK Lighthouse, Customs or Metrological Station	0.5	300, 450, 600	125	200
3	0.5 TK Ditto	1.0	300, 450, 600	300	450
4	1 IV Station for coast fortifications	1.5	300 to 900	400	600
5	1.5 TK Large Station for harbour work	3.0	300, 450, 600, 900		300 450
6	1.5 TV Ditto	3.0	300 to 1200	500	1000
7	2.5 TK Coast Station for heavy traffic	5.0	600, 900, 1200, 1650	600	1200
8	2.5 TV Station for naval bases or frontier forts	5.0	600 to 2000		450 600
9	5 TK Station for heavy harbour traffic	10.0	600, 900, 1200, 1650	1200	2400
10	5 TV Station for naval flagships or frontier forts	10.0	600 to 2000		750 1500 ¹
11	7.5 TK Ditto	15.0	1000, 1200, 1650, 2000, 3000, 4000	1100	2200
12	10 TK Large Customs and Coast Station	20.0	1200, 1650, 2000, 3000	1500	3000
13	15 TK Ditto	25.0	1200, 1650, 2000, 3000	1800	3600
14	25 TK Large Land Station for Transatlantic work	48.0	1200, 1650, 2000, 3000, 4000	3000	4000
15	35 TK Ditto	60.0	2000 to 10,000	(Work across Australia)	2000 2500
16	80 TK Ditto	160.0	2000 to 10,000	America to Europe (Sayville)	Europe to America and Africa
17	100 TK	200.0	2000 to 20,000	Europe to America, Alaska, Africa and Australia	Europe to America (up to 10,000 miles)
18	High-Frequency Machine Station	—	Up to 20,000	Limited by International Regulations to 50 km.	—
19	Telefunken compass	—	300, 450, 600	—	—

¹ This great variation of range with rise of power is due to employment of a very high mast for this particular station.

INTRODUCTORY

SHIP STATIONS.		Day. Over Sea.	Night. Over Sea.
20	0'05 TK Launch Station		100
21	0'1 LK Station for fishing boats, pleasure and coasting vessels	300, 450	180
22	0'2 TK station for small passenger boats, cargo vessels and submarines	300, 450, 600	200
23	0'5 TK Station for passenger, cargo vessels and torpedo boats	300, 450, 600	450
24	1 TK Station for passenger and cargo vessels	300, 450, 600	} 400
25	1 TV Station for large torpedo boats, destroyers, etc.	300 to 900	
26	1'5 TK Station for passenger and cargo vessels or cruisers	300, 450, 600, 900	1200
27	2'5 TK Station for mail vessels	300, 450, 600, 900	} 750
28	2'5 TV Station for cruisers or liners	600 to 2000	
29	5 TK Station for passenger vessels	600, 900, 1200, 1500, 1800	} 1200
30	5 TV Station for battleships	600 to 2000	
31	7'5 TK Large Ship Station	1000, 1200, 1650, 2000, 3000, 4000	3200
32	10 TK } 12'5 TK	1200, 1800, 2000, 3000, 4000, 5000	4000 ?
33	15 TK	300, 450 and 600	6000 ?
34	Emergency set		200
MILITARY STATIONS.			
35	0'03 TBK Balloon Station	300, 450, 600	50
36	0'04 TPK Tourist Station	300, 400, 450	40
37	0'03 TAeK Aeroplane Station	300, 450, 600	50
38	0'1 TAeK . Ditto	300, 450, 600	200
39	0'1 TMK Airship Station	300, 450, 600	200
40	0'3 TMK . Ditto	300, 450, 600	400
41	0'3 TPK Pack Saddle Station	300, 450, 600, 900	75-100
42	0'3 TLK Landing Station	300, 450, 600, 900	75-100
43	0'1 TAK Light Automobile Station	300, 450, 600, 900, 1200	160
44	0'1 TFK Light Portable Field Station	300, 450, 600, 900, 1500	250
45	1'5 TFK Portable Field Station	600, 900, 1200, 1500	350
46	1'5 TAK Automobile Field Station	600, 900, 1200, 1500	350
47	2'5 TAK Heavy Automobile Station	600, 900, 1200, 1500, 1800, 2000	600

The technical position just before the outbreak of the late war, and on completion on ten years' work, was given in an article in the "Telefunken Zeitung" as follows:—

"The development is not in any way finished, but on the contrary is being vigorously continued. The receiving Lieben intensifier has just been introduced for intensifying weak signals, both for Telephony and Morse signals. Its method of use for wireless apparatus has been much improved by the Telefunken Company after many trials, so that this apparatus can now be used for exciting undamped oscillations. The intensified undamped vibrations so produced have for the first time an absolutely constant amplitude and frequency unlike the arc-lamp method, where, as is well known, a certain amount of variation occurs within certain limits. Also with the Lieben intensifier, undamped vibrations of very short wavelengths can be produced, for example, for a 300 metre wave. This apparatus will no doubt have a great effect both for practical installations and for research purposes.

"The development of large stations has also not reached its limits. The work of the last few years has shown that the influence of light over long ranges depends upon the application of very long wavelengths necessitating long aerials, and also that for long ranges enormous amounts of energy are necessary if the communication is to be kept up during daylight. As these effects depend, in the case of spark transmitters upon the low-spark frequency, requiring a greater use of energy, the use of undamped wave generators is obtaining at the present day great importance. Such undamped vibrations can now be reproduced directly by a high-frequency machine.

"The Telefunken Company have built a high-frequency machine, the principle of which is to obtain high-frequency current from a relatively low period of alternation, by means of manifold doubling of the period. Such a machine, requiring 20 kw. primary energy, has been under test for a year at Nauen station, and to-day gives for the 1750 meter wave 4 kw. in the aerial and with the 3500 wave as much as 11 kw. It therefore corresponds in its classification to the so-called spark-excited 10 TK station. Such a high-frequency machine is to be installed upon the S.S. 'Vaterland,' the largest vessel in the world, when this is completed. By means of the high-frequency machine it has been rendered possible for the first time to obtain a practical wireless telephony, and to do away with the use of the heavy current microphone. The new world's record was achieved by excellent

transmission of language from Nauen to Vienna over about 600 km., in which a telephony intensity of 10 ohms was obtained, with very great clearness for consonants. The Secretary of State for the German Post Office, Excellence Kraetke, was present upon the 27th July, when he spoke by means of wireless telephony from Nauen to Norddeich (450 km.).

"In consequence of these results Telefunken has constructed a 200 kw. high-frequency station which is now in use.

"At this early stage it is naturally impossible to say what will be the importance of the high-frequency machine in practice. It, however, appears to be highly probable that particularly for large land stations this machine will be used, while for smaller and medium size stations the spark-gap method will be concurrently used. The last ten years have shown that each method has its special advantages, and that corresponding to the many requirements obtained in practice, both methods will be used one with the other."

Just before the outbreak of war, a standardised valve wireless telephone installation was for the first time about to be put on the market for ship and portable stations.

The progress during the war was chiefly in relation to the adoption of continuous wave stations and valve intensifiers to aeroplanes and portable trench installations, the first development of valve interception trench sets (for the interception of messages sent along buzzer trench lines by the Kiebnitz earth method), and of valve position-finders for guiding and detecting aircraft.

One noticeable development was the production of a highly vacuated "hard" valve by Meissner, an important improvement which was, however, obtained independently by Langmuir in the United States and by the French Army. Further details of this work is given later.

Soon after the outbreak of war, a land station of the largest type was completed at Funibashi for the Japanese Government and successfully communicated, via Honolulu, with San Francisco.

The large Arco high-frequency machine at Nauen also carried out experiments with Sayville, near New York, before the entrance of the United States into the war.

During the war the Nauen station was further enlarged by two 400 kw. Arco high-frequency machines which, in parallel, produced the enormous value of over 800 kw. of high-frequency energy in the aerial. With such an enormous aerial energy Nauen is now by far the most powerful wireless station in the

world, and regularly attains extremely long ranges to Australia, Alaska, and the Far East. High-power valve transmitters are also now installed.

The Growth of the English Quenched-Spark System.— Since the early days of wireless telegraphy many companies, other than that of Marconi, had, up to 1910, endeavoured to establish wireless telegraphy systems. The immediate result was a great deal of patent disputes and litigation.

The company which had the greatest success was that of the Lodge-Muirhead system, and according to the International List of Radio-telegraphic Stations there are now in existence two stations of this system in England, four in British India, one in British Guinea, one in British West Indies, and two in Zanzibar.

Other systems which attempted to gain, without much success, a footing in England, were those of De Forest, Poulsen, and Rochefort.

In 1910, Messrs. Siemens Bros. & Company of Woolwich took up the British patent rights of the Telefunken Company, which system had by this date been largely adopted, with the exception of England, everywhere else throughout the world.

During the first year of their entry into commercial wireless engineering, very little actual installation work was carried out, since it was necessary to organise a large part of their Woolwich works in order to later carry out mass production; and what was far more important, to design new apparatus to meet the special requirements of British shipping.

In order to be able to carry out long range and other testing work, a large experimental station was erected at Woolwich, which had in 1912 become of sufficient interest to warrant a visit by the delegates of the Third International Conference on Radio-telegraphy, held in London, of that year.

The large number of technical engineers and the engineers of shipping companies who later visited this station, and were often given demonstrations of the new apparatus by the present writer, were always much impressed by the complete absence of noise during transmission. If arrangements were made to work alternately upon an open gap and a quenched gap, they were impressed by seeing the immediate doubling of the aerial current, thus demonstrating the double efficiency of the new gap. This result has not been obtained by the various types of disc-dischargers, since produced to obtain the advantage of a musical note, but which do not simultaneously obtain increased efficiency or absence of noise.

The technical side of the wireless section was in charge of Mr. H. A. Machen, an English engineer, who had some years before gone to Germany to take charge of the Experimental Laboratory of the Telefunken Company when the first Telefunken spark gap was manufactured, and had later left this company to join another engineering company in London.

The results of this experimental work, in which, later, Mr. W. Legg, B.Sc., and the present writer assisted, were very far reaching rather than spectacular, and were to ultimately lead to a greatly modified and improved system of wireless telegraphy for the British mercantile marine.

This work tended more towards the engineering side than towards the purely scientific, though many such problems were encountered and solved.

The first ship to be fitted in 1910 was the "Titan" of Messrs. A. Holt & Co., Ltd., of Liverpool, and other ship installations followed.

For the first time in England a system of guaranteed ranges were given for each installation, which experience soon showed was by no means a maximum range, but on the contrary was expected by the manufacturers to be at least doubled, and gave great disappointment if not exceeded threefold. Wireless transmitters were also, for the first time in England, classified by the more scientific method of aerial output instead of energy consumption.

Another great advantage of this system was immediately recognised by shipowners, namely, that they did not have to provide for each installation an expensive sound-insulated cabin, but on the contrary, the stations could be installed in any existing cabin.

Perhaps the chief difficulty encountered at this period, well remembered by the writer, was, as already mentioned on page 7, a refusal on the part of other British ships to intercommunicate, and this was naturally a greater disability with the Quenched-Spark stations on British ships than with the Telefunken stations on foreign shipping. Fortunately the 1912 International Conference was soon to sweep away this opposition to progress, and whilst for some time afterwards sporadic attempts at refusal to intercommunicate were encountered, these were stated to be unauthorised and soon died away. After the first ships were fitted (March, 1911), patent actions were commenced (20th October, 1911) by the Marconi Company for

infringement of their "7777" patent, a counter-action being commenced by Siemens for the Marconi Company's infringement of the Braun patent for the use of coupled circuits, for which they now had the British rights.

These actions never proceeded to the courts, since the Marconi and Telefunken Companies having meanwhile agreed to acknowledge each other's past patents and exchange future patents, the cases automatically lapsed.

Meanwhile, much progress had been made at Woolwich by Messrs. Siemens Bros. in spite of the difficulties introduced by the Telefunken-Marconi agreement which, whilst proving of mutual advantage to these two companies, rendered the introduction of the Quenched-Spark system in England more difficult, since, for concessions in other parts of the world, the desire of the Telefunken Company was to entirely abandon the British field to the Marconi Company.

Of special note at this period was the adoption of the Quenched-Spark system for a series of stations in British North Borneo by the Government of that Colony. The Eastern Telegraph Company, whose technical staff were well able to appreciate the merits of the new system and whose advisory engineer was the late Mr. W. Duddell, then President of the Institution of Electrical Engineers, a name prominent in wireless history, also decided to instal Quenched-Spark land stations at Lagos and Freetown. More recently, 1919, the Crown Agents for the Colonies have decided to instal such apparatus in a new station at Zanzibar.

A second English land station was installed for the London Telegraph Training College, with the object of providing trained operators for the Quenched-Spark installations, and whilst this well-known training college did for some years provide sufficient operators, the ship installations were being so rapidly taken up and the demand for operators, therefore, so great, that the most important wireless training colleges have since found it beneficial to instal Quenched-Spark installations for training purposes.

In the region of ship installations for which this system was more especially designed, very many warships then building in England installed the new system, and these included the two warships celebrated for their close-quarter battle in the English Channel, namely, H.M.S. "Faulkner" and "Broke," originally built for the Chilian Navy and afterwards taken over by the British Navy.

Five battleship stations were also built at Woolwich which, it is believed, are the largest ever installed on board ship, since the main transmitter (of which there were three in all) radiated no less than 15 kw. of electrical energy, as compared to .5 kw. to 1.5 kw. radiated by a commercial station.

The outbreak of hostilities in 1914 swept away the last remnants of the connection with the Telefunken Company which had for long been purely nominal.

As with all other engineering firms, attention was devoted to military work and it was not possible to carry out ship work. The author, since 1914 in military service, came across the Siemens' apparatus on the Western Front and at home training depôts. The adoption of the Quenched Gap and the Quenched-Spark receiver by the British Army was well evidenced by military apparatus, present at a lecture given just after the cessation of hostilities, at the Institution of Electrical Engineers by Lieut.-Colonel Cuzens, R.E., and entitled "The Development of Army Wireless during the War".

With a return to Peace conditions the English manufacturers of the Quenched-Spark system are again able to devote their attention to ship installations, and the demands for this system are rapidly increasing, so that in a few years it is likely to find extensive use in the British mercantile marine. This condition was foreshadowed just previous to the war by a supplement issued to the official list, which showed that the major proportion of stations equipped since the issue of the previous supplement were Quenched-Spark stations.

The author, not now in Messrs. Siemens' service, understands that much new technical research is being carried out at Woolwich, of the nature of direction-finding apparatus for ships, call-signal apparatus, and valve transmitters for telephony.

In reply to a letter requesting particulars of recent Telefunken apparatus, the author was informed that no communications whatever have been received from that company since 1914, and they are therefore unable to furnish the same. It would therefore appear that the Quenched-Spark system, whilst of German origin, has been so greatly developed as to render it entirely independent of the very slight assistance given by the Telefunken Company before the war.

Adoption of the Quenched-Spark System in Other Countries.—It is unnecessary to enumerate the countries which have adopted the Telefunken system, since these include every civilised country in the world, with the exception of Italy and

France, which utilise a native system, employing a similar Quenched Gap.

Of special note, however, is the case of Japan, which originally purchased several large ship stations from Messrs. Siemens, and for whom a large land station was erected at Funibashi by the Telefunken Company.

The very large mercantile marine of Japan, which formerly employed chiefly Marconi apparatus, and which has grown enormously during the late war, now appear in the official list of radio stations as "Teishinsho Musical Quenched Spark".

Patent rights in Japan are peculiar, and it would appear that in wireless, as in many other branches of engineering, the Japanese have followed their usual practice of first purchasing apparatus from foreign manufacturers, and then if results warrant it, adopting such apparatus to their own needs, with very little fear of patent litigation. China has also extensively adopted Telefunken apparatus.

In Australia, as already mentioned, large land stations were erected by the Telefunken licensees for the Australian Government at Perth and Freemantle, a procedure which, on technical and economical grounds, was warmly defended by the Australian Parliament. Many Australian ships were also fitted with Telefunken apparatus. The later stations were erected by the Government itself under the direction of their engineer, Mr. Basillie, and are given in the official list as "Australian Commonwealth". The author believes these Government stations embody all the best results of the original Telefunken installations.

New Zealand similarly followed Australia's example, and had a number of Telefunken land stations and ship stations erected.

Of particular interest in this part of the world was the erection of a Telefunken station on Marquarie Island, to work with the Mawson Antarctic Expedition.

In Egypt the official list of stations now shows a Telefunken land station.

The United States of America have also adopted the Telefunken system or the Quenched Gap to a large extent for both ship and land stations. The largest is Sayville, near New York, which previous to the entrance of the United States into the late war could be heard, a greater part of every day and night, working with the Nauen station in Germany.

The U.S.A. Government were one of the earliest purchasers of Telefunken military and naval stations. The present Government system is a composite one, and many stations employ the Quenched Gap.

It is of great interest to notice in the "Journal of the Institute of American Radio Engineers" that the American Marconi installations in each case employ both a Quenched Gap of the Telefunken type, and the English Marconi Company. According to Eccles, the Quenched Gap is preferred to the rotary discharger of the mother company.

It would therefore appear that Japan, Australia, and the United States of America, and more recently the British Army, have followed what has for long been the present writer's view, namely, that they should refuse to be bound down to any particular system of wireless telegraphy, but should themselves employ capable practical engineers, specialising in wireless telegraphy.

Such engineers would be able, instead of installing any particular system of wireless telegraphy *en bloc*, to evolve a system fulfilling the particular needs of their own country, and to embody the best features of all the various commercial systems, paying if necessary for the use of any commercial patents.

The more recent inception of the "Parliamentary Committee on Radio-telegraphy" in England, to report on the proposed British Imperial Scheme Stations, and on wireless progress in general, would make it appear that this is now the official British view. Such a committee will undoubtedly again bring British wireless telegraphy to a leading position in the world, in spite of the attacks recently levelled at its chairman, Sir Henry Norman, M.P., one of the English scientific investigators, whose opinions are based on unbiased scientific observations of progress throughout the World.

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CHAPTER II.

THE THEORY OF WIRELESS TRANSMITTERS, WITH SPECIAL REFERENCE TO QUENCHING AND THE RESULTS OF QUENCHING.

BEFORE describing the actual apparatus and installations of practical wireless telegraphy, it will be of interest to consider the fundamental physical phenomenon of the electrical circuits used for this purpose. We shall commence with the simplest ideal case and progress to the present-day dual circuit, due to Braun, and now in universal use, then deal with the effects due to the still later method of quenching, or shock-excitation, rendered necessary by the use of the dual circuit.

Whilst the first portion of this chapter must necessarily be mathematical, to those not so inclined, little difficulty will be experienced in the later practical portion, although some mathematical knowledge is essential for the correct interpretation and realisation

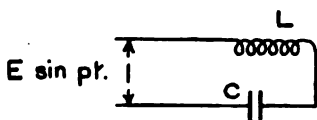


FIG. 1.

of the actual physical phenomena.

Undamped Oscillations.—Circuit having capacity and inductance but no resistance (Lord Kelvin). (Fig. 1.)

Let a circuit having inductance L and capacity C be excited by a periodic source of electrical pressure $E \sin . pt.$

Then we have—

$$\left. \begin{array}{l} \text{Electro-magnetic voltage } L \frac{di}{dt} \text{ due to inductance} \\ + \text{ electro-static voltage } \frac{q}{c} \text{ due to capacity} \end{array} \right\} \begin{array}{l} \text{equals periodic} \\ \text{voltage of} \\ \text{source} \\ E \sin . pt.. \end{array}$$

where q = quantity of charge and i = current at time t .

Mathematically this is—

$$L \frac{di}{dt} + \frac{q}{c} = E \sin . pt.$$

We shall only consider the instant when the applied e.m.f. is zero and the circuit has energy due to its own physical properties of inductance and capacity.

Then $L \frac{di}{dt} + \frac{q}{c} = 0$
 and since

$$i = \frac{dq}{dt} \text{ and } \frac{di}{dt} = \frac{d^2q}{dt^2}$$

our equation becomes—

$$\frac{d^2q}{dt^2} + \frac{q}{LC} = 0.$$

This is a very well-known type of differential equation representing "simple harmonic motion" and satisfied by

$$q = Q \cos . pt.$$

By differentiating this twice and substituting in the original equation, we find the equation is satisfied, providing

$$p = \frac{1}{\sqrt{LC}}.$$

The time of oscillation is then easily seen to be

$$t = 2\pi\sqrt{LC}.$$

If we plot values of "q" and "i" we shall find that we obtain a curve as follows:—

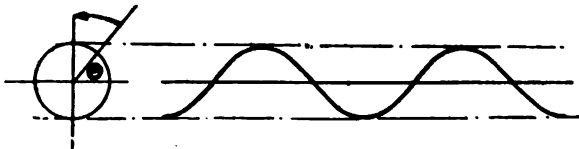


FIG. 2.

showing that the oscillation of q continues indefinitely.

This case represents, very nearly, an aerial directly excited by a high-frequency machine, such as of the Arco type, where continuous sustained oscillations occur. Although energy is lost, partly by radiation from the aerial and partly by resistance and dielectric losses, these are made good by energy drawn, via the machine, from the prime source of energy, so that for consecutive complete oscillations of energy, the amount of energy is constant.

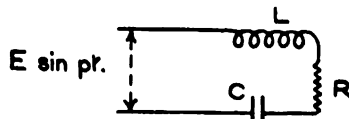


FIG. 3.

Damped Oscillations.—Circuit having inductance, capacity, and resistance (Lord Kelvin). (Fig. 3.)

In practice we find oscillations excited in a circuit do not

continue indefinitely, as in the previous section, but die out. We are so led to inquire as to the effect of resistance.

In this case the applied electrical pressure is partly taken up in overcoming the resistance R , to an extent Ri , where i is current in the circuit.

Our equation of e.m.fs. now becomes—

$$L \frac{di}{dt} + Ri + \frac{q}{c} = E \sin . pt,$$

or for the instant when $E \sin . pt = 0$

$$L \frac{di}{dt} + Ri + \frac{q}{c} = 0$$

and, as before, substituting for $\frac{di}{dt}$ and i in terms of q —

$$\frac{d^2q}{dt^2} + \frac{R}{L} \frac{dq}{dt} + \frac{q}{LC} = 0.$$

This differential equation is satisfied by—

$$q = Ae^{at}$$

whence

$$\frac{dq}{dt} = aAe^{at}$$

and

$$\frac{d^2q}{dt^2} = a^2Ae^{at}.$$

Substituting these values in the original equation, to find the conditions for this value to satisfy, our equation becomes—

$$Aa^2e^{at} + \frac{R}{L}Aae^{at} + \frac{Ae^{at}}{LC} = 0$$

or—

$$a^2 + \frac{R}{L}a + \frac{1}{LC} = 0$$

a quadratic, for which the value of a is given by—

$$a = -\frac{R}{2L} \pm \sqrt{\frac{R^2}{4L^2} - \frac{1}{LC}}.$$

If $\frac{R^2}{4L^2} > \frac{1}{LC}$ the roots are real and q may be written—

$$q = Ae^{a_1t} + Be^{a_2t}$$

where A and B are constants which may be determined and a_1, a_2 are the real roots of the quadratic for a . These roots are clearly both negative.

To determine A and B call Q the total quantity of charge at time $t = 0$, and remember that $i = \frac{dq}{dt} = 0$ at time $t = 0$ whence—

$$A = Q \frac{a_2}{a_2 - a_1} \text{ and } B = - Q \frac{a_1}{a_2 - a_1}$$

and
$$q = \frac{Q}{a_2 - a_1} (a_2 e^{a_1 t} - a_1 e^{a_2 t}).$$

The variation of q with t may be graphically represented as follows :—

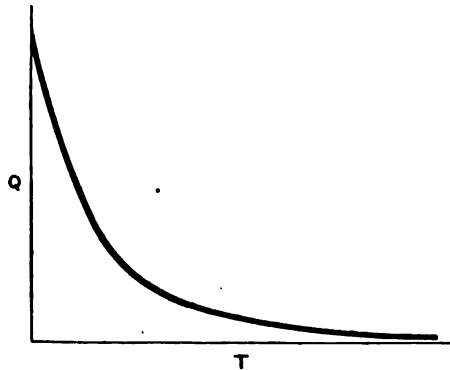


FIG. 4.

As this is not an oscillatory discharge we shall not further consider this case, but it should be noted that the “dead beat” discharge is determined by $R > \sqrt{\frac{4L}{C}}$, so that, resistance being the determining factor, to promote good oscillation in a circuit, the resistance should be kept at the minimum practically possible.

Regarding the matter purely from the actual phenomena, if the resistance is great, the electrical energy is rapidly converted, owing to the resistance to heat energy. Electrical oscillations therefore die out very quickly and the discharge tends to become dead beat.

When $R < \sqrt{\frac{4L}{C}}$ the roots of our equation for a are unreal and may be written—

$$\begin{aligned}
 a_1 &= a + j\beta \\
 a_2 &= a - j\beta \text{ where } j = \sqrt{-1} \\
 a &= -R/2L \\
 \beta &= \sqrt{\frac{1}{LC} - \frac{R^2}{4L^2}}
 \end{aligned}$$

In this case the general solution is—

$$q = e^{at} (C \cos \beta t + D \sin \beta t),$$

where C and D are constants to be determined.

This we can do by remembering that $q = Q$ at the instant before discharge occurs, i.e. when $t = 0$. Inserting these values we obtain—

$$Q = C, \text{ since } \cos \beta t = 1 \text{ and } \sin \beta t = 0 \text{ when } t = 0.$$

To obtain D, differentiate once and put $\frac{dq}{dt} = i = 0$, since no current is then flowing, i.e.

$$\begin{aligned}
 0 = \frac{dq}{dt} &= ae^{at}(C \cos \beta t + D \sin \beta t) + e^{at}(-C\beta \sin \beta t \\
 &\quad + D\beta \cos \beta t).
 \end{aligned}$$

$$\therefore 0 = aC + \beta D \text{ and since } C = Q,$$

$$D = -\frac{a}{\beta}Q,$$

hence—

$$q = Qe^{at}(\cos \beta t - \frac{a}{\beta} \sin \beta t).$$

In most cases the ratio $\frac{a}{\beta}$ is small in consequence of the smallness of R, and may be neglected, in which case we have—

$$q = Qe^{at} \cos \beta t \text{ where } \beta = \frac{1}{\sqrt{LC}}.$$

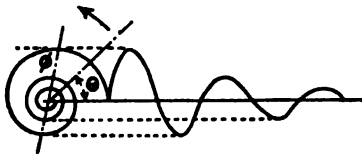


FIG. 5.—Graphic representation of damped oscillatory discharge.

In the same manner that simple harmonic motion can be represented by developing a circularly rotating vector, this variation of q can be similarly represented by developing a logarithmic spiral vector as in Fig. 5.

It is seen that the oscillation gradually dies out and the ratio of the value of any crest to the preceding one is a constant known in physics as the

“decrement,” or in wireless practice the “damping,” since the decrease of q is due to the damping effect of resistance.

To obtain an expression for the e.m.f. at any instant we have to remember that, if v is e.m.f. at condenser plates at time t , Q and V initial charge and e.m.f. respectively, then $Q = CV$ and $q = Cv$. Hence $q = Qe^{at} \cos \beta t$ becomes—

$$v = Ve^{at} \cos \beta t$$

but the frequency $n = \frac{1}{2\pi\sqrt{LC}}$ and $2\pi n = p$

hence substituting $\frac{1}{\sqrt{LC}}$ for β

$$v = Ve^{at} \cos pt.$$

This case exactly represents a plain aerial having a spark gap (such as used by Hertz and Marconi) where energy is originally drawn through an induction coil, and at the instant after the spark discharge occurs, the aerial may be considered as a single circuit, having a large resistance owing to the presence of the spark gap, which dissipates energy as heat so that the electrical oscillations quickly die out.

Modern Dual or Coupled Circuits.—As already mentioned, the first paragraph represents the variation of energy which occurs in a wireless aerial directly excited by an alternating, but constant, source of energy. An alternator for such a purpose offers great mechanical constructional difficulties, and whilst many forms have been constructed, they are not extensively used, except with a few largely experimental stations.

The second paragraph is the case of a plain aerial, and, since it was for some years used by Marconi, is known extensively as a “Marconi aerial”.

Such an aerial (Fig. 6) is now prohibited by international wireless laws, since, owing to the high resistance of the spark gap, it suffers from the impossibility of being sharply tuned, and therefore emits waves of varying wavelength over a wide wave range, only a part of which can be utilised at the receiving station, the remainder causing a great deal of unnecessary interference to other stations.

Braun, in 1898, took out a patent which became the property of the Telefunken Company, in which, for the first time, two circuits (Fig. 7) were used. In one the high-resistance spark gap was situated, and in the other, forming the aerial circuit, the resistance could be kept very low, and very sharply-tuned oscillations could in consequence be radiated.

As with so many scientific advances, this was not altogether a new discovery since Lord Rayleigh had, in his "Theory of Sound," 1878, dealt with the analogous physical case for sound, and Overbeck, in the "Annalen der Physik," had dealt with coupled circuits for the electrical case in 1895.

The circuit in which the oscillations are generated in the modern-day receiver are best described as the "primary" or "excitation circuit," since it excites oscillations by a spark discharge, which are radiated from the "secondary" or "aerial circuit".

Transfer of energy from excitation to aerial circuit takes place by means of a transformer or "coupling," which in Marconi practice is known as the "jigger," a term, however,

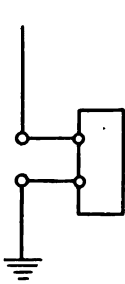


FIG. 6.—Marconi aerial.

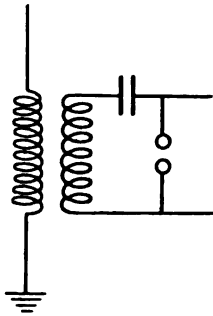


FIG. 7 a.—Braun aerial (magnetic coupling).

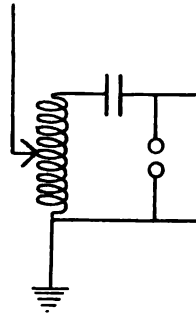


FIG. 7 b.—Braun aerial (direct or static coupling).

conveying little information and best avoided. The effect of this coupling may be regarded as providing an "electrical sieve," since the tuned aerial circuit draws only that oscillatory energy from the excitation circuit which has the same oscillatory period, whereas it does not draw energy when the oscillatory period is very little different. The energy so passed to the aerial circuit is then radiated with a nearly constant wavelength.

The amount of energy which passes from one circuit to another, via the coupling, depends upon the degree of mutual inductance, this itself depending upon the number of turns common to both circuits and their distance apart, i.e. to the mutual inductance. There is therefore a degree in the coupling (K) usually defined as—

$$K = \frac{L_m}{\sqrt{L_1 L_2}}$$

where L_m = mutual inductance and L_1 and L_2 = self inductances of the two circuits.

Should the excitation and aerial circuits have a large number of common closely-wound turns, a large transference of energy takes place from one circuit to the other and the circuits are said to be "close coupled". In the ideal case (nearly reached in an induction-coil primary and secondary), all the energy is then transferred from one circuit to the other, so that $K = \frac{L_m}{\sqrt{L_1 L_2}}$ tends to unity, or as it is usually expressed, 100 per cent. This, however, does not permit of the sieve-like action, and the oscillations in the secondary are not sharply tuned, i.e. of the same wavelength.

In the case where the inductive transfer is small, owing to the use of a few turns, not relatively close together, the circuits are said to be "loose coupled" and K tends to zero, i.e. 0 per cent. Tuning is then exceedingly sharp, but little transference of energy from one circuit to the other occurs.

We have up to the present spoken of the aerial circuit as radiating energy upon a single wavelength. This is, however, far from the case, at least two definite wavelengths being obtained (and can be demonstrated by the wavemeter) as the result of mutual interference of the two circuits, after energy has been imparted to the aerial circuit.

If we denote mutual inductance by a new term, M , equating e.m.fs. as in the previous case, we obtain for the complete case of the dual circuit (Fig. 8)—

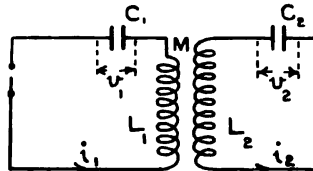


FIG. 8.

$$L_1 \frac{di_1}{dt} + M \frac{di_2}{dt} + \frac{q_1}{c_1} + R_1 i_1 = E \sin . pt$$

for the excitation circuit, and

$$L_2 \frac{di_2}{dt} - M \frac{di_1}{dt} + \frac{q_2}{c_2} + R_2 i_2 = 0$$

for the aerial circuit. The second e.m.f., namely, $M \frac{di_1}{dt}$, is due to the e.m.f. induced by the excitation circuit and is balanced by the remaining terms, since work is done by it in overcoming resistance whilst forming an inductive magnetic field, and charging the capacity.

As our present purpose is merely to demonstrate mathematically the presence of a dual wave in such a transmitting arrangement, we will neglect the forcing term $E \sin . \rho t$ of the excitation circuit, and to further simplify matters, neglect the resistances. This can be done legitimately for the aerial circuit, and whilst great in the excitation circuit, is relatively small in comparison to the inductance and capacity of this circuit. It is evident that if in such a simplified system we find the presence of a dual oscillation in the system when the excitation circuit is in "free oscillation" with respect to the forcing term $E \sin . \rho t$, the correct phenomenon will not be more simplified when we include this term, but on the contrary more complex.

With the foregoing reservation our two equations now reduce to—

$$L_1 \frac{di_1}{dt} + M \frac{di_2}{dt} + \frac{q_1}{c_1} = 0$$

$$L_2 \frac{di_2}{dt} - M \frac{di_1}{dt} + \frac{q_2}{c_2} = 0$$

respectively, and since

$$\frac{q}{c} = v \text{ and } i = -C \frac{dv}{dt},$$

we can write these as—

$$(C_1 L_1 D^2 + I)v_1 + C_1 M D^2 v_2 = 0$$

$$(C_2 L_2 D^2 + I)v_2 - C_2 M D^2 v_1 = 0$$

where $D \equiv \frac{d}{dt}$.

$$\therefore \{(C_1 L_1 D^2 + I)(C_2 L_2 D^2 + I) - C_1 C_2 M^2 D^4\} v_1 v_2 = 0.$$

The solution to this differential equation is $v_1 \propto e^{j\rho t}$, where $j = \sqrt{-I}$ and whence—

$$Dv_1 = j\rho v_1$$

$$D^2 v_1 = -\rho^2 v_1$$

$$D^4 v_1 = \rho^4 v_1.$$

Inserting these values we obtain

$$(-C_1 L_1 \rho^2 + I)(-C_2 L_2 \rho^2 + I) - C_1 C_2 M \rho^4 = 0$$

$$\text{or } (C_1 C_2 L_1 L_2 - C_1 C_2 M^2) \rho^4 - (C_1 L_1 + C_2 L_2) \rho^2 + I = 0$$

$$\text{or } L_1 L_2 C_1 C_2 (I - K^2) \rho^4 - (C_1 L_1 + C_2 L_2) \rho^2 + I = 0$$

since we have defined $K = \frac{M}{\sqrt{L_1 L_2}}$.

Also let $T_1 = 2\pi\sqrt{L_1C_1}$ and $T_2 = 2\pi\sqrt{L_2C_2}$

and let $\rho = 2\pi n = \frac{1}{\sqrt{LC}} = \frac{2\pi}{T}$

hence our equation reduces to a quadratic in T,

$$(1 - K^2) \frac{T_1^2 T_2^2 (4\pi^2)^2}{(4\pi^2)^2 T^4} - \left(\frac{T_1^2}{4\pi^2} + \frac{T_2^2}{4\pi^2} \right) \frac{4\pi^2}{T^2} + 1 = 0$$

i.e. $T_1^2 T_2^2 (1 - K^2) - (T_1^2 + T_2^2) T^2 + T^4 = 0$

whence $T^2 = \frac{T_1^2 + T_2^2 \pm \sqrt{(T_1^2 - T_2^2)^2 + 4K^2 T_1^2 T_2^2}}{2}$.

This equation for T must necessarily give two values, namely—

$$T' = \sqrt{\frac{(T_1^2 + T_2^2) - \sqrt{(T_1^2 - T_2^2)^2 + 4K^2 T_1^2 T_2^2}}{2}}$$

and $T'' = \sqrt{\frac{(T_1^2 + T_2^2) + \sqrt{(T_1^2 - T_2^2)^2 + 4K^2 T_1^2 T_2^2}}{2}}$.

Since it is well known that—

$T = \frac{1}{n}$ and $n\lambda$ (the wavelength) = velocity of light = a constant,

we may write these two equations in terms of λ , namely—

$$\lambda' = \sqrt{\frac{(\lambda_1^2 + \lambda_2^2) - \sqrt{(\lambda_1^2 - \lambda_2^2)^2 + 4K^2 \lambda_1^2 \lambda_2^2}}{2}}$$

and $\lambda'' = \sqrt{\frac{(\lambda_1^2 + \lambda_2^2) + \sqrt{(\lambda_1^2 - \lambda_2^2)^2 + 4K^2 \lambda_1^2 \lambda_2^2}}{2}}$.

The result of this sufficiently lengthy mathematical treatment proves *the existence of at least two wavelengths in coupled circuits*. Those requiring the complete solution when resistance is considered are referred to Overbeck's paper already mentioned.

As already mentioned the presence of two waves in the aerial is objectionable, and we shall later describe Wien's method of preventing or "quenching" one of these waves.

We have seen our values of T' and T'' only contain one quantity under our control, namely, $K = \frac{M}{\sqrt{L_1 L_2}}$, and, to make our analysis complete, we will see whether we can in practice choose K in order to obtain a single wave.

Case 1.—If the two circuits are tuned to resonance for maximum transfer of energy, then

$$\lambda_1 = \lambda_2 = \lambda, \text{ hence—}$$

$$\lambda' = \lambda \sqrt{1 + K}$$

$$\lambda'' = \lambda \sqrt{1 - K}, \text{ hence values of } \lambda' \text{ and } \lambda'' \text{ differ.}$$

It is therefore impossible to cause the aerial to radiate only one wave, merely by making the circuits resonant.

Case 2.—If the circuits are in resonance ($\lambda_1 = \lambda_2 = \lambda$) and close coupled so that $K = 1$,

$$\text{then } \lambda' = \sqrt{\lambda_1^2 + \lambda_2^2}$$

$$\lambda'' = 0.$$

We so obtain only one wavelength. All the energy is then transferred from excitation to aerial circuit, but the effect of coupling is neutralised. The aerial emits energy explosively of *all* wavelengths, and it would be just as advantageous to dispense with the coupling and work on an open aerial.

Case 3.—Let the circuits be in resonance and K be zero, i.e. the circuits are loose coupled.

Then $\lambda' = \lambda'' = \lambda$ and we have only one wavelength, but K being zero or small practically no energy is transferred from the excitation circuit to the aerial circuit for radiation purposes, which is necessary in practice.

We therefore see that *if we require the aerial to radiate only one useful wavelength* (since a receiving aerial can only be tuned to one wavelength at any instant), *it is impossible to obtain this result, with efficiency, by tuning or the variation of coupling*, since in the first case, two wavelengths are produced; in the second case, one wavelength is produced, but the beneficial effect of coupling is eliminated; and in the third case, one wavelength is produced but little or no energy is radiated.

We have considered above the two circuits coupled magnetically. It is necessary to state here, as mentioned later, that the circuits may be direct or electro-statically coupled. With such a method of coupling, two waves also appear in the coupled system. The solution for such an electro-static coupling is very similar to the magnetic case and may be found in Drude's "Physik des Aethers," page 482, and compared to the magnetic case on page 473 of the same work.

Before dealing with a method by which radiation on a single wavelength and large transfer of energy can be obtained, we will first discuss the variations which occur, when the source of energy and resistance which we have hitherto neglected are taken into account.

RESONANCE.

Resonance of a Single Circuit.—Returning to our original equation of paragraph 2, namely—

$$L \frac{di}{dt} + Ri + \frac{q}{c} = E \sin . qt \quad . \quad . \quad (1)$$

and putting $v = \frac{q}{c}$ and $i = C \frac{dv}{dt}$

we obtain $CL \frac{d^2v}{dt^2} + CR \frac{dv}{dt} + v = E \sin qt \quad . \quad . \quad (2)$

Let $a = \frac{R}{2L}$ and $\beta = \frac{1}{CL} = p^2 + a^2$

whence—

$$\frac{d^2v}{dt^2} + 2a \frac{dv}{dt} + v\beta = E\beta \sin . qt.$$

This differentiated twice gives—

$$\frac{d^4v}{dt^4} + 2a \frac{d^3v}{dt^3} + \frac{d^2v}{dt^2}\beta = - E\beta^2 \sin qt,$$

which, added to the foregoing, after this has been multiplied by q^2 , removes the sine term and gives—

$$\frac{d^4v}{dt^4} + 2a \frac{d^3v}{dt^3} + (p^2 + a^2 + q^2) \frac{d^2v}{dt^2} + 2aq^2 \frac{dv}{dt} + (p^2 + a^2)q^2v = 0.$$

Put $v = e^{mt}$

then $\frac{dv}{dt} = me^{mt}$, $\frac{d^2v}{dt^2} = m^2e^{mt}$, etc.,

and we obtain the auxiliary biquadratic—

$$\begin{aligned} m^4 + 2am^3 + (p^2 + a^2 + q^2)m^2 + 2aq^2m + (p^2 + a^2)q^2 &= 0 \\ \text{or} \quad (m^2 + q^2)(m^2 + 2am + p^2 + a^2) &= 0 \\ (m^2 + q^2)((m+a)^2 + p^2) &= 0. \end{aligned}$$

$$\therefore m_1 = \pm jq$$

$$m_2 = -a \pm jp \quad (j = \sqrt{-1}).$$

Hence the solution is—

$v = P \sin qt + Q \cos qt + e^{-at}(A \sin . pt + B \cos . pt)$
a result which on differentiation and substitution in (2) will be found to satisfy it identically and which we may write—

$$v = V \sin (qt - \phi) + V^1 e^{-at} \sin (pt - \theta) \quad . \quad . \quad (3)$$

where—

$\phi = -\tan^{-1} \frac{Q}{P}$; $\theta = -\tan^{-1} \frac{B}{A}$; $V = \sqrt{P^2 + Q^2}$ and $V^1 = \sqrt{A^2 + B^2}$,
 A, B, Q, and P being constants.

This result shows that the e.m.f. of the circuit has two oscillations:—

(a) A forced oscillation $V \sin (qt - \phi)$ of frequency equal to that of the applied electrical pressure.

(b) A free oscillation due to the energy previously imparted to the circuit but not already dissipated by resistance—

$$[V'e^{-at} \cos (pt - \theta)],$$

which disappears at an exponential rate.

To determine the variation of energy with difference of frequency in the two components, differentiate (3) twice and substitute values of $\frac{dv}{dt}$ and $\frac{d^2v}{dt^2}$ so found, in the original equation (2), neglecting terms containing e^{-at} since these die out very quickly in comparison to the sine terms, i.e. the free vibration may only have a period of one-millionth per second while forcing vibration may have a period of one-hundredth per second, so that time of former is negligible in comparison to the time of the latter.

Hence we obtain—

$$\text{CL}[V(p^2 - q^2 + a^2) \sin (qt - \phi) + V2qa \cos (qt - \phi)] = E \sin qt,$$

$$\text{or, CL}[V\sqrt{(p^2 - q^2 + a^2)^2 + (2qa)^2} \sin (qt - \phi - \psi)] = E \sin qt,$$

$$\text{therefore, } V = \frac{(p^2 + a^2) \cdot E}{\sqrt{[(q^2 - p^2) - a^2]^2 + [2qa]^2}}$$

Suppose R is small, so that $a^2 = \left(\frac{R}{2L}\right)^2$ may be neglected in comparison with p^2 , and remembering—

$$\frac{p}{q} = \frac{n_2}{n_1} = x \text{ and } I = CVq \text{ then—}$$

$$I = \frac{E}{L\sqrt{q^2(1 - x^2)^2 + 4a^2}}$$

which is the value of the current, which would be read by a suitable instrument in the oscillatory circuit and is a maximum when $x = \frac{n_1}{n_2} = 1$.

If we insert a suitable hot wire ammeter and plot its readings against x , or what is the same thing, keep the frequency n_1 of the source q constant and plot n_2 (which will differ with the wave

length as determined by means of a wavemeter) by variation of the physical constants of the circuit, i.e. inductance or capacity, we obtain a curve as shown in Fig. 9, such a curve being known as a "resonance" curve.

It shows that when the ratio of frequencies (Δ) or wavelengths is unity, we obtain maximum flow of current (B_m) in the oscillatory circuit, any deviation from unity causing a rapid decline of current whether the ratio of wavelengths is above or below unity.

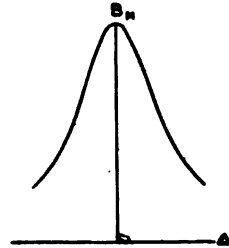


FIG. 9.

This is a general physical case of the principle of tuning enunciated for wireless technique by Sir Oliver Lodge. In this wireless case, however, the source of energy is a transmitting wireless station and the flow of energy occurs in the aerial of a receiving station, which may be separated by hundreds of miles.

Hence by transmitting energy on a single wavelength we are able to sharply tune the distant receiver to receive maximum possible energy. Since the current and energy decline rapidly, as the ratio of wavelengths differs slightly from unity, the radiation of energy from the transmitting station will not affect to appreciable amounts differently tuned receivers at other stations. Also sharply tuned radiations from other transmitting stations will not appreciably affect the receiving station originally mentioned. *Hence to avoid "jamming" or mutual interference of wireless stations we must transmit on sharply defined wavelengths which are detected by sharp resonance at receiving stations.*

The injurious effect of resistance in oscillatory circuits is again seen if we obtain strongly damped curves (Fig. 10) these becoming very flat and even distorted so that the critical wavelength for maximum transfer of energy is not sharply defined.

Resonance of Coupled Circuits, having Damping, i.e. Resistance (V. Bjerknes). (Fig. 11.)

On page 43 we obtained the expression $Ve^{-at} \cos pt$, for the voltage across the condenser terminals of an oscillatory circuit. Since in the present case this is the e.m.f. in the primary circuit producing oscillations in the secondary, we may write—

$$L_2 \frac{di_2}{dt} + R_2 i_2 + \frac{q_2}{c_2} = Ee^{-at} \cos . p_1 t,$$

the right-hand side being the forcing term.

To avoid purely mathematical difficulties we shall assume there is no lag of the secondary current behind the primary current, i.e. the e.m.f. is E when $t = 0$.

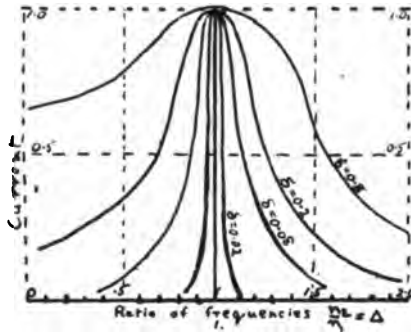


FIG. 10.—Effect of damping ($\delta =$ damping).

Writing the above equation in terms of voltage ($v = \frac{q}{c}$);

$$\frac{d^2 v_2}{dt^2} + \frac{R_2}{L_2} \frac{dv_2}{dt} + \frac{v_2}{L_2 C_2} = \frac{E}{C_2 L_2} e^{-a_1 t} \cos. p_1 t$$

and substituting as before, $2a_2$ for $\frac{R_2}{L_2}$, $p_2^2 + a_2^2$ for $\frac{1}{C_2 L_2}$;

$$\frac{dv_2^2}{dt^2} + 2a_2 \frac{dv_2}{dt} + (p_2^2 + a_2^2)v_2 = \frac{E}{L_2 C_2} e^{-a_1 t} \cos. p_1 t.$$

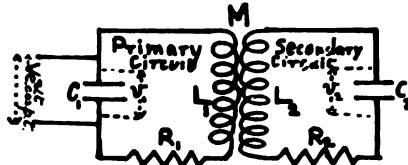


FIG. 11.

To solve this equation, differentiate twice with respect to time, multiply original by $(p_1^2 + a_1^2)$ and first differential by $2a_1$ and add, whence—

$$\begin{aligned} \frac{d^4 v}{dt^4} + 2(a_1 + a_2) \frac{d^3 v_2}{dt^3} + [(p_1^2 + a_1^2) + (p_2^2 + a_2^2) + 4a_1 a_2] \frac{d^2 v_2}{dt^2} \\ + [2a_2(p_1^2 + a_1^2) + 2a_1(p_2^2 + a_2^2)] \frac{dv_2}{dt} + [(p_2^2 + a_2^2)(p_1^2 + a_1^2)] v_2 = 0. \end{aligned}$$

Replacing, as on page 49, differential coefficients by values of m , we get a biquadratic for which the roots are—

$$\begin{aligned} & - a_1 \pm j\beta_1 \\ & - a_2 \pm j\beta_2 \end{aligned}$$

and the solution is of the form—

$$v_2 = V_1 e^{-\alpha_1 t} \sin(\beta_1 t + \theta_1) + V_2 e^{-\alpha_2 t} \sin(\beta_2 t + \theta_2).$$

Similarly by considering the removal of the original voltage, i.e. ($E \sin \rho t = 0$) and the energy of the secondary as reacting back on the primary circuit, we can obtain a similar expression for v_1 .

As on pages 46 and 47, where we did not take resistance into consideration, we find that, with circuits having resistance, there are two distinct waves differing in frequency ρ and damping α , one $V_1 e^{-\alpha_1 t} \sin(\beta_1 t + \theta_1)$ being a forcing wave, and the other a free wave, $V_2 e^{-\alpha_2 t} \sin(\beta_2 t + \theta_2)$, both dying away at an exponential rate.

To determine the maxima amplitudes V_1 and V_2 , as before differentiate v_2 twice, and substitute the values of $\frac{d^2 v_2}{dt^2}$ and $\frac{dv_2}{dt}$ and v_2 in the original equation, then making use of the trigonometrical formula—

$$\sqrt{A^2 + B^2} \cos \rho t = A \cos(\rho t + \theta) + B \sin(\rho t + \theta) \text{ if } \tan \theta = -\frac{B}{A}$$

and that $\frac{1}{L_2 C_2} = \rho_2^2 + \alpha_2^2$ we obtain—

$$V_1 = \frac{(\rho_2^2 + \alpha_2^2)E}{\sqrt{[(\rho_2^2 - \rho_1^2) - (\alpha_2 - \alpha_1)^2]^2 + 4\rho_1^2(\alpha_2 - \alpha_1)^2}}$$

To find V_2 of the free wave put $t = 0$ for $v = 0$ in solution for v , differentiate and again put $t = 0$ for $\frac{dv}{dt} = 0$, the result being—

$$V_2 = \frac{(\rho_2^2 + \alpha_2^2) \sqrt{\rho_2^2 + (\alpha_2 - \alpha_1)^2} \cdot E}{\rho_2 \sqrt{[(\rho_2^2 - \rho_1^2) - (\alpha_2 - \alpha_1)^2]^2 + 4\rho_1^2(\alpha_2 - \alpha_1)^2}}$$

If we substitute these values of V_1 and V_2 in the original equation and differentiate to obtain i (since $i_2 = C_2 \frac{dv_2}{dt}$), square and integrate with regard to t , since

$$I^2 = \int_0^\infty i^2 dt = C_2^2 \int_0^\infty \left(\frac{dv}{dt}\right)^2 dt$$

neglecting powers of $(\rho_1 - \rho_2)$ and $(\alpha_1 - \alpha_2)$ we obtain for the

mean square current in the secondary (which a suitable hot-wire ammeter would read)—

$$I^2 = \frac{E^2}{16L_2^2} \frac{(a_1 + a_2)}{a_1 a_2} \frac{I}{(\rho_1 - \rho_2)^2 + (a_1 + a_2)^2}$$

a result obtained by Bjerknes and also by Drude, by different methods.

When $\rho_1 = \rho_2$ and we have resonance, the value of I^2 is easily seen to be—

$$I^2 = \frac{E^2}{16L_2^2} \frac{I}{a_1 a_2 (a_1 + a_2)}$$

showing the necessity of keeping resistances ($a = \frac{R}{2L}$) small to obtain a maximum value of I^2 .

We can easily show this value of I^2 to have two components, remembering $I = CV\rho$ and substituting in our values of V_1 and V_2 we get—

Total current in } = Current of forced + Current of free
aerial } oscillation + oscillation,
or

$$I = \frac{\rho_1 \cdot E}{L_2 \sqrt{[(\rho_2^2 - \rho_1^2) - (a_2 - a_1)^2]^2 + 4\rho_1^2(a_2 - a_1)^2}} + \frac{\sqrt{\rho_2^2(a_2 - a_1)^2} \cdot E}{L_2 \sqrt{[(\rho_2^2 - \rho_1^2) - (a_2 - a_1)^2]^2 + 4\rho_1^2(a_2 - a_1)^2}}$$

This enables us to interpret the resonance curve obtained when we insert a hot-wire ammeter in our secondary of aerial circuit and plot values of $\frac{n_1}{n_2}$, or what is the same thing, when keeping n_1 constant, plotting values of wavelength obtained by the wavemeter, against values of I^2 , the result being a curve of the type—

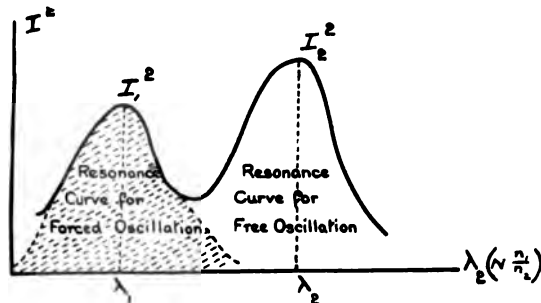


FIG. 12.

This shows us that, with coupled circuits, which of necessity to avoid radiation of energy upon many wavelengths, we are compelled to adopt, *we obtain in the aerial two oscillations of very different wavelengths having maxima λ_1 and λ_2 .*

Since, at any instant, a receiving station can only be tuned to one wavelength (the largest λ_2), *the energy of the other maximum wavelength λ_1 , represented by the shaded area (since energy is proportional to the square of the current) and which is large in proportion to the energy of λ_2 , is totally wasted* and only gives rise to "jamming," or interference, at other neighbouring receiving stations.

THE NECESSITY OF QUENCHING.

On pages 46 and 47 we showed by mathematical analysis the existence of two oscillations in a secondary or aerial circuit, since we obtained two different periods of oscillation.

From consideration of resonance, on page 53, we obtained a value for the secondary voltage, which was seen to have two components, each of which represented a distinct oscillation. We also found that the total current in the aerial had two components, which explained the double peak of the resonance curve, obtained in practice for coupled circuits.

The actual presence of this dual oscillation can be actually shown by use of the Braun cathode tube.

If this is done we obtain curves for the variation of voltage in the two circuits as follows :—

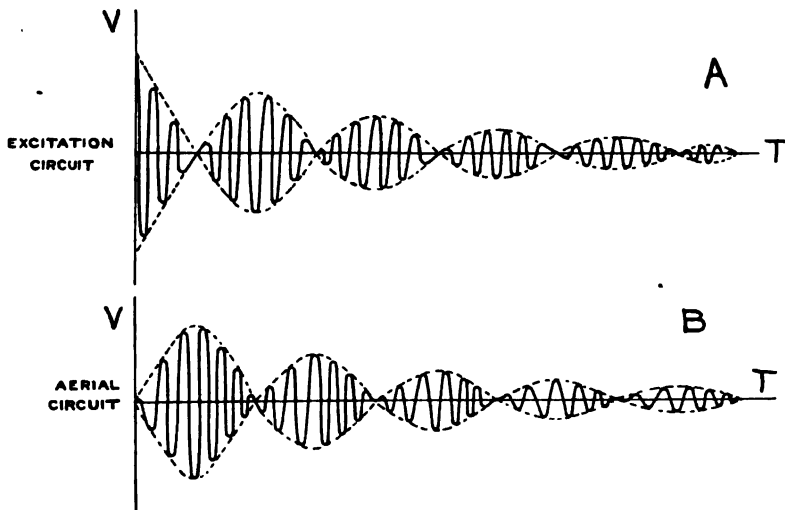


FIG. 13.—Oscillations in open-spark transmitter (Wien).

Those familiar with the theory of sound will at once recognise that the aerial and excitation circuits both oscillate with "beats". There are, in each circuit, two oscillations of different periods and damping, which as they agree or differ in phase give rise to electrical "beats" similar to beats obtained with mechanical systems vibrating to produce sound.

Since the energies of the oscillations in each circuit sometimes assist and sometimes oppose each other, we must always have a loss of energy in the latter case.

The forced oscillation in the aerial is produced by the further transfer of energy from the excitation circuit, and, as the latter is an alternating source of current, for short periods we will have the forcing voltage equal zero.

This will allow energy to surge back from the aerial circuit, since the voltage of the latter, owing to the free oscillation, is not zero, and the spark gap will be bridged, so causing a great loss of energy owing to its high resistance, which dissipates the electrical energy as heat and light energy.

Further advance of time permits the oscillations produced in the excitation circuit to again excite the aerial, this cycle continuing until all the energy is dissipated either by radiation from the aerial or by resistance losses at the spark gap.

If we can now discover some means whereby immediately the excitation circuit has first imparted its energy to the aerial circuit, the resistance of the spark gap of the former circuit is made so great that energy surging back into it is unable to bridge the spark gap, all the energy connected magnetically and statically with the two circuits will (neglecting the very small resistance of the aerial circuit) only have one means of dissipation, namely, by useful radiation from the aerial circuit. Since the forced oscillation of the excitation circuit ceases to exist, *all the energy will be radiated on one wavelength, namely, the natural wavelength of the aerial circuit.*

The act of stopping the flow of energy in the excitation circuit is known as "quenching," since it is brought about by preventing or quenching the return spark. Also since all the energy is transferred from the excitation to the aerial circuit after the passage of a single spark, the aerial circuit is said to be "impact" or "shock excited".

Quenching is best brought about by use of a special form of spark gap described in detail in the next section.

The effects of quenching are very noticeable in practice.

Considering first the variations of voltage in the two circuits, these are shown as follows:—

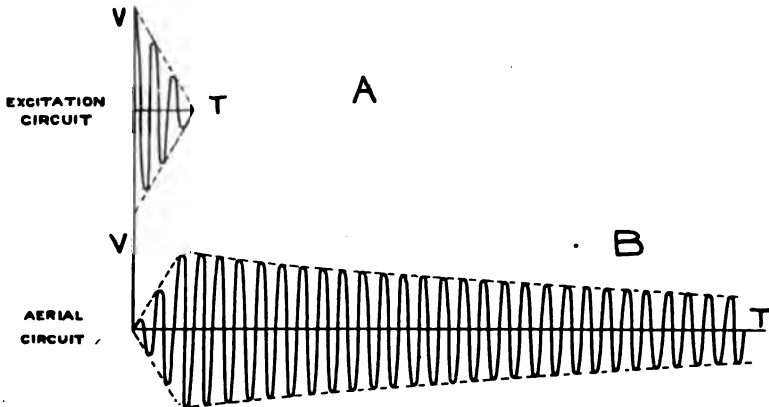


FIG. 14.—Oscillations in 'Quenched-Spark transmitter (Wien).

It will be noticed the oscillations of the excitation circuit are practically non-existent, and that the train of oscillations of the aerial has a very low logarithmic decrement, and therefore a long persistence. Beats do not occur, and there is therefore no waste of energy in beat production.

The aerial oscillations tend therefore to continuous oscillations and the area of the curve they produce, being proportional to voltage (or current), determines the energy. The great increase in aerial energy will be at once recognised, when compared to the oscillation of the aerial when the return sparking is not quenched and beats occur.

Consider now the effect of quenching on the resonance curve.

Curves for oscillations produced by open and Quenched-Spark gaps are given on pp. 334 and 335 of Fleming's "Principles of Electric Wave Telegraphy" from actual experiments by Fleming and Dyke.

As, however, unless one recognises the differences in coupling in the original curves, the whole difference between open and quenched gaps is apt to be overlooked, the author has taken the liberty of redrawing them in a series of curves (Fig. 15), each of which show the open and quenched-gap curves for the same particular degrees of coupling.

In the case of the open-gap curves when quenching does not occur, the curve will be found to have two distinct peaks of very

different wavelength and low current value, which is proportional to the energy radiated.

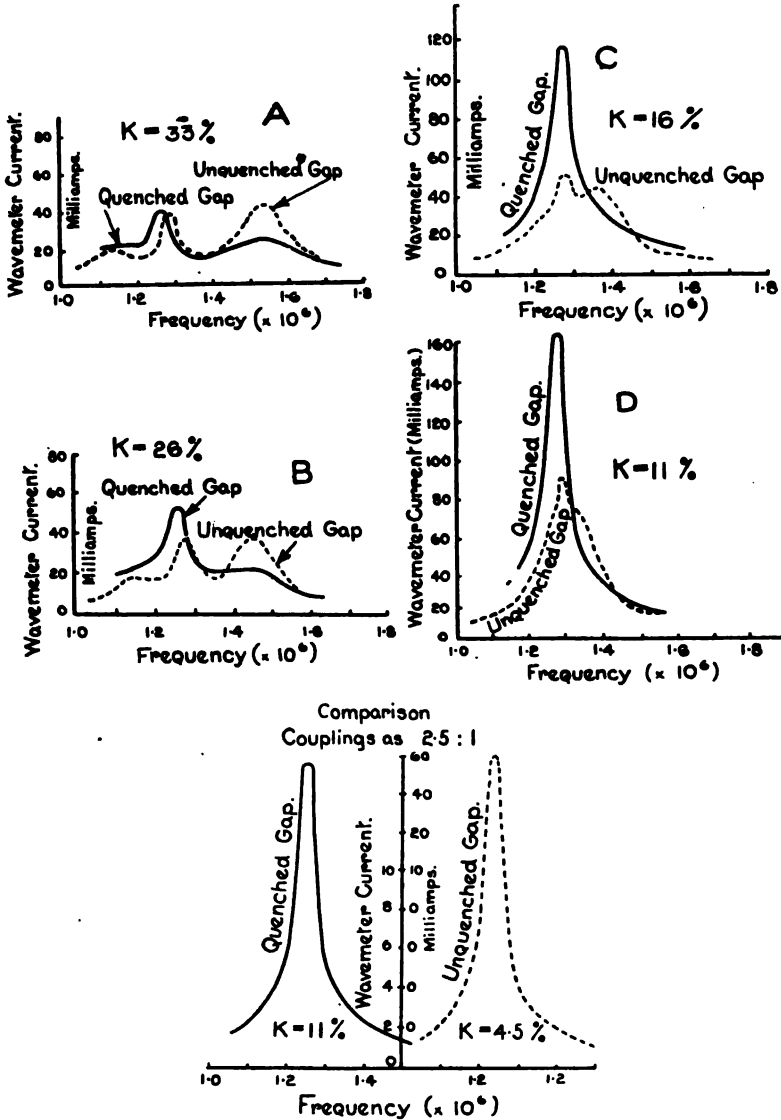


FIG. 15.—Resonance curves for coupled circuits (Fleming redrawn).

For a coupling of 26 per cent., with the quenched gap, there is only one sharply defined peak (the other having nearly dis-

appeared at a coupling of 26 per cent.). Compared with the open-spark curve of similar coupling, its current value is much greater, and therefore more energy is radiated upon a sharply defined wavelength.

In the case of the double peaked open-gap curves, a receiving station can only resonate to one wavelength, and therefore the energy of the other is totally wasted and only serves to cause interference to other stations.

The last curves of this series show the difference of coupling necessary to obtain the same current effect with open and quenched gaps. These couplings are, according to Fleming, 11 per cent. for the quenched gap as opposed to a much weaker coupling of 4.5 per cent. for the open gap. This means that the coupling must be weakened and therefore a less transference of energy from excitation and aerial circuit takes place, and to render the aerial currents equal much greater energy in the prime circuit must be present. According to Fleming's figures it would be presumably necessary to use $\frac{11}{4.5} = 2.5$ times the prime energy

to obtain the same aerial energy, i.e. with the quenched gap the efficiency is about 75 per cent. if we take the usual value of 25 per cent. for the open gap, a figure for the quenched gap which has been questioned by its opponents.

The above curves also show the effect of coupling, if either the open or quenched-gap curves of the series are considered by themselves.

It is theoretically possible to tune a receiving station to respond to both the emitted waves of an open-spark station. With difficulty this could be obtained in practice for communication with one particular station only, but since these two waves may mutually vary under different conditions at the same transmitting station, it involves much greater skill in operating technique to utilise both the waves. Kimauri has carried out experiments in this connection, but practice showed the signals to be much weaker than with a loose coupled receiver responding to only one peak.

Curves showing the effect of coupling due to Wien are shown in Fig. 16.

As the coupling is increased the quenching becomes more pronounced, but that there is a certain maximum coupling, above which any increase in coupling decreases quenching and gives a smaller aerial current. The best coupling is 18 to 19 per cent. measured as already defined.

Having now shown the scientific necessity for quenching we will deal with the actual means by which it is obtained in practice.

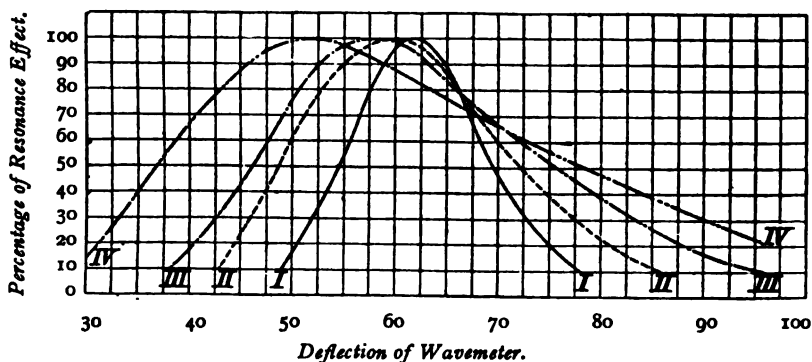


FIG. 16.—Resonance curves with Quenched-Spark for various couplings and secondary wave constant.

Coupling.	Primary Wavelength.	Secondary Wavelength.	Coupling.	Primary Wavelength.	Secondary Wavelength.
I. ... 0.05%	1340	1340	III. ... 9%	1294	1340
II. ... 7%	1312	1340	IV. ... 18.2%	1230	1340

The Quenched-Spark Gap.—We have now discussed the presence of a dual oscillation which occurs in coupled circuits, introduced by Braun for their very superior emission of oscillations of definite wavelength, but which suffered from the fact that at least two waves were present. We have also seen that if we can prevent or quench the oscillation in the excitation circuit, only a single wave, natural to the aerial will be emitted. Also the wave train will be much longer sustained and therefore give off more energy, which we have seen by Fleming's figures may be as much as 75 per cent. as compared to 25 per cent., the large difference being due to energy which would, with an open spark, be dissipated in repeatedly breaking down the spark gap, during back surges of energy, but will now be available for radiation.

The discovery of a method of effecting quenching was made by Max Wien in 1906, who showed that if a series of small spark gaps were used instead of a long single gap, very efficient quenching resulted. Wien's discovery was taken up by the Telefunken Company, who soon evolved a commercial type of gap shown in Fig. 17 a.

The gap consists of a number of small spark gaps formed by circular silver-faced copper discs, accurately machined and separated by thin mica rings.



FIG. 17 a.—View of spark dischargers.
(See p. 60.)

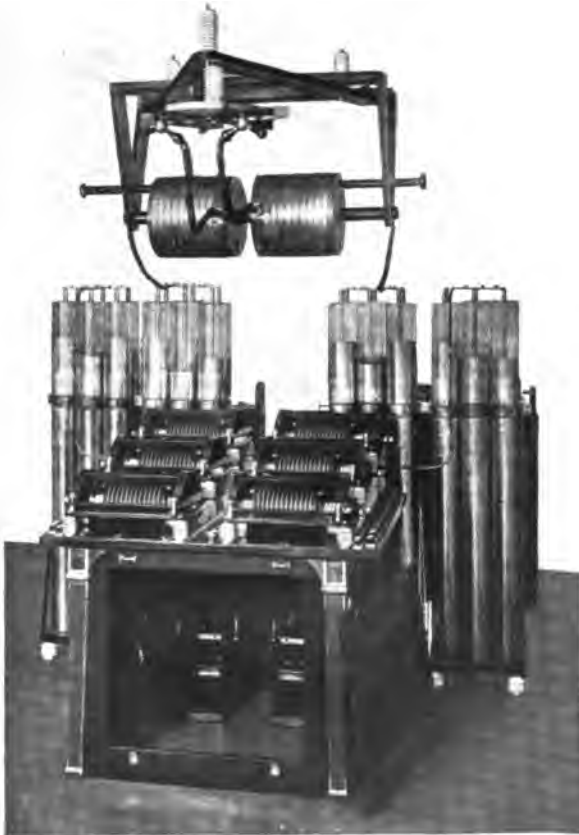


FIG. 17 b.—Gap battery for large station in Australia.
(See p. 61.)

[To face p. 60.]

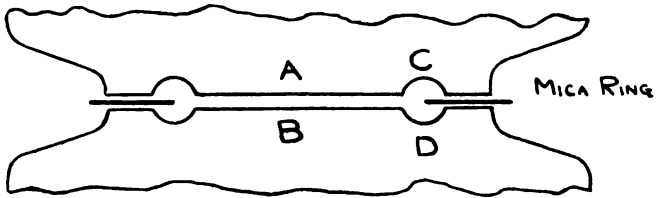


FIG. 18.

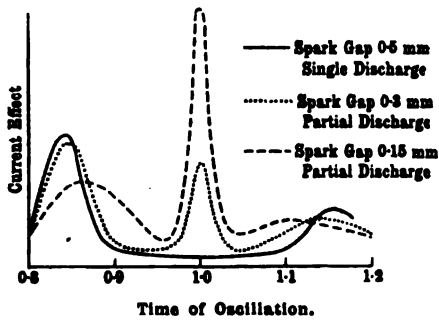


FIG. 19.—Curves showing the importance of small gaps in producing the single wave by quenched sparks.

[To face p. 61.

Between each spark gap is placed a larger copper or brass disc, the function of which is to conduct away the heat from the sparking surfaces, and to radiate it into the air. For very large stations this radiation is facilitated by blowing a swift current of air through the gaps. The gaps are manufactured in sets and their arrangement and method of cooling is shown in Fig. 17 *b*, for an extremely large station employing a battery of gap sets.

Various explanations have been given as to the precise action of this form of spark gap. According to Fothergill¹ and others a spark occurring between the two electrodes at a position AB (Fig. 18) is, owing to the presence of a magnetic field due to the passage of current, rapidly forced in an axial direction towards the periphery of the electrode.

On arrival at the increased sparking distance CD the applied voltage is insufficient to bridge this distance and the spark is extinguished or quenched.

Certainly in support of this view is the fact that the presence or absence of the groove CD has a great effect upon the quenching, as determined by aerial current readings. Also at one period the Telefunken Company employed a form of spark-gap plate in which the number of channels were considerably increased, by turning a number of concentric grooves upon the gap face.

Another explanation of the quenching effect is that the employment of a large flat electrode surface decreases the tendency towards sparking since no concentration of the field occurs, as is the case of spherical or pointed electrodes, of which the electrical capacity of the points is infinitely small. Also such flat surfaces rapidly absorb the ions, the emission of which from the electrode surface and their passage across the gap constitute the electrical current. With such a rapid absorption directly the applied alternating voltage falls below the peak value, the spark is unable to be maintained and very rapid quenching occurs, assisted by the metal electrodes and the cooling discs rapidly radiating the heat developed by the passage of current, so diminishing the emission of ions from the electrodes due to purely thermionic phenomena, which rapidly increases with rise of temperature.

Wien in his classical paper found the quenching effect to be dependent upon the coupling between excitation and aerial

¹ "Electrical Review," p. 947, 5th June, 1914.

circuits, a result which might be expected, since with a very tightly coupled circuit, the voltage due to back surges of energy from aerial to excitation circuit will be greater, the greater the degree of coupling, and so there will be an increased tendency for back surges of energy to break down the gap resistance. Therefore, with long spark distances, quenching can only be obtained by loose-coupling the two circuits, whilst with small spark-gap distances the circuits can be more tightly coupled. It will be better to subdivide the total sparking distance into a number of smaller spark gaps, the electrodes of each sub-gap adding to the quenching effect.

Ultra-violet light thrown upon the spark gap also interferes with good quenching, the action being the same as for overheating, since ultra-violet light acting upon a metallic surface produces liberation of ions. It has been proposed to determine the discharge at will by the intermittent action of ultra-violet light, so causing intermittent increased ionisation.

A modification of the original quenched gap has been introduced, in which the gap is surrounded by air at high pressure which hinders ionisation and so promotes good quenching. The influence of the chemical constitution of the gas is small, providing this is inert and so does not attack the metal electrodes.

Since the emission of negative ions differs according to the metallic element from which they are produced, it is to be expected that the quenching will depend upon the nature of the circular electrodes. This is found to be the case, silver and zinc being the best metals for facing the gap plates and magnesium the worst. The proper sweating of the silver upon the copper discs is a commercial secret, and unless this is carried out by a certain method, air bubbles are apt to form beneath the silver surface and when subjected to the high tension discharge, the plates rapidly wear away.

Fleming states that he has found the efficiency of a quenched gap to fall off rapidly after use, this probably being due to bad sweating of the silver-copper junctions, or to the silver layer not being homogeneous.

The author's experience, both personal and obtained by questioning a large number of operators, actually working Quenched-Spark stations over long periods, is that the efficiency of the gap improves as the initial smoothness wears off and most operators prefer a somewhat dirty sparking surface, possibly because the allotropic form of silver formed upon the surface

promotes the quenching, or that a pitted surface is more quenching in nature.

The gaps rarely require replacement if properly manufactured, gaps used for commercial stations engaged in mediumly heavy traffic frequently lasting a year or more. As already mentioned, stations radiating more than 5 kw. from the aerial have their spark gaps air cooled if necessary for continued working, but nowadays not by means of water, as Fleming states, the insulation of such a water current offering great practical difficulties.

The distance apart of the spark surfaces as a determining factor of the quenching, will be seen from the curves in Fig. 19 due to Wien¹ (p. 61).

The correct distance of .2 mm. in practice is approximately fixed by the thickness of the insulating mica discs, but this can be slightly varied at wish by means of the horizontal screw (Fig. 17 *a*) which acts against a glass or porcelain "pressure disc" and is worked by a tommy bar.

The number of gaps to be used is determined by the energy to be radiated. The gaps are usually made up in sets of eight or twelve, and metallic clips are provided to short circuit any number of gaps desired. Increase in the number of gaps causes the energy delivered to the aerial to increase in approximately geometrical progression, i.e. with two gaps the aerial radiates four times the energy radiated with one gap, etc.

Other Attempts at Quenching.—The high aerial efficiency attained by this gap has led to its being copied, various gaps of a slightly modified form, depending for insulation on paper, oil, etc., having been introduced.

One noticeable attempt to obtain the effect of quenching is by rapid mechanical separation of the spark electrodes to increase the gap resistance and so cause quenching (rotary gaps).

To take a specific instance, it is stated that "an alternator revolves at 3000 r.p.m. and there are 10 spokes on the discharger; this gives 500 discharges per second and creates a quenched musical spark discharge".

¹ This series of curves will be found in many wireless books. It first appeared in Wien's paper in the "Annalen der Physik," and in the "Jahrbuch der drahtlose Telegraphie," Vol. I. It appeared in England in the "Electrician" of 10th November, 1911, where owing to an error the word "Swingungsdauer" was translated as "Ratio of the Frequencies in the two circuits" instead of "length of time of oscillation". This mistake has always been repeated (until the present moment) when abstracted from the "Electrician". It is not a resonance curve, and if it is interpreted as such, it either proves the reverse of the actual phenomenon it is stated to show, or is entirely meaningless.

It is granted such an arrangement causes a musical spark, which was first introduced by the Telefunken Company as a subsidiary advantage rendered possible by the quenched gap, and has since been largely copied.

To investigate the quenching properties we have the fundamental relation—

$$n\lambda = \text{velocity of light} = 3 \times 10^8 \text{ metres per sec.}$$

from which we see that for a 300 metre wave, to produce absolute quenching, i.e. during the first half cycle of the alternation, the electrodes must be separated within a period

$$\left(\frac{3 \times 10^8}{3 \times 10^3}\right) \times 2 = \frac{1}{2 \times 10^6} \text{ second.}$$

Assume that the diameter of the moving electrode is .5 centimetres, a practical diameter of such a discharger of the author's experience.

The problem is to remove this in a period of $\frac{1}{2 \times 10^6}$ sec., i.e. we must obtain a peripheral speed of

$$\frac{.5}{\frac{1}{2 \times 10^6}} = 10^4 \text{ metres per second.}$$

To obtain such a speed at 3000 r.p.m., i.e. 50 revs. per second requires a diameter of

$$50 \times \pi d = \times 10^4 \text{ metres}$$

from which $d = 63.5$ metres.

We therefore see that with the apparatus mentioned, absolute quenching or any approach to it in the slightest degree is not attained, since the actual diameter is not (in the case of a commercial product dealt with by the author) more than 30 cms. diameter.

The only alternatives are:—

1. To decrease the size of the electrode. This is not practicable, and indeed an electrode of .5 cm. would not carry any very considerable power.

2. Increase the speed of rotation. This is hardly practicable above 3000 r.p.m., and in this case, with the given number of spoke electrodes, the musical note advantage is lost, since the pitch becomes disagreeable or above audible limits. It should be realised increase of speed requires decrease in number of electrodes in order to maintain the same pitch of the note.

We may therefore say, that whilst such an arrangement will produce a musical signal, by no means will it tend to produce a quenched discharge. It is true that the distance between the electrodes is small, but there is nothing to prevent sparking after the electrodes are separating. This is actually what occurs, and the author, who for months used such a discharger in military service, can say that by the noise produced (necessitating a sound-proof cover to partly deaden its intensity), it was evident long distance and therefore non-quenching discharges were occurring, a fact borne out by the efficiency obtained as shown by the aerial reading for the given input.

For small stations, such as the pack military set of the author's experience, an increase of speed is not practicable. With large land stations some approach to quenching might be obtained, but since the general aim of the engineer is to eliminate as many moving parts as possible, which necessitate energy consumption for rotation, mechanical difficulties of lubrication, etc., a non-moving Quenched-Spark discharger of the Telefunken type is much to be preferred.

We have a comparison of the stationary quenched gap of the Telefunken type and the rotating musical discharger of the Marconi type in the ship installations of the American Marconi Company, regarding which Eccles says:—

“In these sets two types of spark gaps are provided, either of which can be used as desired. A double pole, double throw switch is provided, so that either spark gap can be inserted in the circuit. One type is known as the quenched gap.¹ The other type is known as the rotary synchronous gap. *In practice the quenched gap is used almost entirely, and the rotary gap merely serves as a spare.*” Such choice is doubtless due to simplicity of operation and greater aerial energy, obtained owing to true quenching occurring with the former.

One further defect of rotary discharges must be mentioned. The rapidly increasing number of ships' stations is more and more rendering it necessary, in order to prevent jamming, that a means be provided in order that the energy can be cut down if required. For example, if a ship has a normal wireless range of 300 miles it is not only uneconomical to use such a transmitter to send a message ten miles, but moreover such a use may cause jamming to every other station within a range of 300 miles. It

¹ Eccles' diagram shows this to be a typical Telefunken quenched gap in all essential points.

is practically certain that to avoid such unnecessary jamming British legislation will shortly be introduced.

With the quenched gap such a diminution of radiated energy is immediately obtained by short-circuiting as many of the gaps as desired, by means of the metal springs provided, so giving a rapid decrease of aerial current, without any change in the emitted note.

With any form of rotary gap, however, the same reduction cannot be obtained, since there is no method of shortening the spark-gap length. The alternating current generator can be, it is true, run at a lower speed to produce a lower output, *but this at the same time reduces the rate of sparking, so that the musical note effect is entirely lost*, which is the chief advantage of such rotary spark gaps.

In practice such rotating spark gaps are always built upon the shaft of the alternating current generator, so that output and spark frequency vary together. Whilst this objection could be overcome by actuating the disc discharger with a small separate motor, to do so only introduces further adjustments and attention to increased apparatus on the part of the operator. This is not to be desired, and in any case this difficulty is not encountered with the true quenched gap.

Results of Quenching.—Although mechanically the Quenched-Spark gap is extremely simple, the results of its use are exceedingly important.

Dealing first with the efficiency, since the oscillations of the excitation circuit are prevented, all the connected energy (both magnetic and static) of the two circuits can only find one outlet, namely, by radiation from the aerial.

There is therefore no great loss of energy due to a multiplicity of sparks due to back surges. The resistance of the aerial being only a fraction of an ohm, negligible in comparison to the gap resistance of many thousand ohms, the latter being removed, allows the useful radiated energy to be more than doubled.

The exact measurement of aerial energy is difficult and open to question, but there are two well-recognised methods, one due to Zenneck and one to Bjerknæs, both world-renowned mathematical physicists, which are considered to be sufficiently accurate for practical comparative purposes.

Figures for the efficiency of Quenched-Spark stations by Zenneck and Bjerknæs' methods are as follows :—

1. <i>Low Frequency—Low Tension.</i>		
(a) Continuous current energy to motor	2950	watts.
Losses in motor	450	"
	<hr/>	
Balance of energy	2500	"
(b) Energy to 500-period generator	2500	"
Losses in generator	500	"
	<hr/>	
Balance of energy	2000	"
2. <i>Low Frequency—High Tension.</i>		
Energy to transformer	2000	"
Losses in transformer	180	watts.
Losses in choking coil	60	"
	<hr/>	
	240	"
Balance of energy	1760	"
3. <i>High-frequency Energy.</i>		
(a) Energy to exciting circuit	1760	"
Losses in spark gap	155	watts.
Losses in condenser	63	"
Losses in self-induction	42	"
	<hr/>	
	260	"
Balance of energy	1500	"
(b) Energy to antenna	1500	"
Antenna current, 13.5 amperes. Antenna resistance with 1200 metre wave = 8.5 ohms. C ² R oscillating energy in the antenna	1500	"
4. High-frequency efficiency	$\frac{1500}{1760}$	= 85 per cent.
5. Efficiency of low-frequency transformer	$\frac{1760}{2000}$	= 88 " "
6. Efficiency of alternator	$\frac{2000}{2500}$	= 80 " "
7. Efficiency of motor	$\frac{2500}{2950}$	= 86 " "
8. Efficiency from antenna to continuous current	$\frac{1500}{2950}$	= 51 " "
9. Efficiency from antenna to alternator	$\frac{1500}{2000}$	= 75 " "

It will be seen that an overall efficiency of 75 per cent. is obtained, and with a station of the Quenched-Spark type, the efficiency is never below 50 per cent., and according to the type of station, rises as high as 75 per cent.

Fleming gives a figure of 25 per cent. to 30 per cent. for the efficiency of stations with open gaps, hence the very superior efficiency, more than double, obtained by quenching, will be at once recognised, and is borne out by his own curves already given.

The fact of quenching allows a far better method of coupling, known as "direct or auto-coupling" to be used.

With this form of coupling (Fig. 7 *b*), (p. 44), the principle

of which is the same as the auto-transformer of general electrical practice, the transformer efficiency ratio is much greater. Since there is a smaller loss of magnetic energy, the efficiency of this coupling is greater than that of the inductive coupling transformer.

Auto-coupling can only be effectively used with Quenched-Spark stations, since sharply defined wavelengths are required. With the multiplicity of wavelengths obtained by the open-spark method, auto-coupling would destroy the "sieve-like" action of the coupling.

According to Fleming, "It is, however, not quite so easy to produce in a direct-coupled antenna oscillations of two frequencies as in the case of an inductively coupled antenna. The reaction of the antenna on the energising or reservoir circuit (excitation circuit) on which this duplexing of the frequency depends, is less well marked in the case of direct-coupled antenna than in the case of the inductively-coupled one." This might be better expressed by stating that it is impossible to close couple an open-spark transmitter, by the use of a direct coupling, since the coupling so loses its filtering effect, whilst the Quenched-Spark permits of direct coupling, since the need of the filtering effect is not so great. Whilst it is thus not quite so easy to produce dual oscillations by direct coupling, this is the last thing which it is desired to produce in either an open or quenched-gap transmitter, whether coupled directly or magnetically.

With auto-coupling, our mathematical equations used to show the existence of dual oscillation of magnetically coupled circuits, require modification. Drude has worked out the complete theory of coupled circuits with auto-coupling, and shown, as would be expected, that the production of dual oscillation still occurs, identical with the case for magnetic coupling, and similarly for high efficiency quenching is necessary.

Another important advantage of quenching is that by this means a musical note can be produced, offering greater audibility at the receiving station.

Almost universally, wireless reception at the present day is carried out by the conversion of electrical energy to mechanical energy in the form of movement of a telephone diaphragm, each movement of which, due to the integration of the energy of each spark, produces a "click" to our aural sense.

Particularly in the tropics, and at dawn and sunset, reception by telephone is difficult owing to natural electrical disturbances, or "atmospherics," producing so much disturbance in the aerial and

receiving telephones, that the clicks due to a sending station are often completely undistinguishable.

If, however, we can produce a sufficiently rapid succession of clicks, a musical note will be heard in the telephones. Atmospherics being extremely irregular and unmusical, the ear can accommodate itself to the musical note, and the disturbing effect of atmospherics, unless very intense, is practically eliminated.

As already mentioned each click in the telephones is due to the energy radiated at each spark, one of which is produced at each peak of the voltage of the generator feeding the oscillatory circuits, i.e. two sparks per cycle.

To obtain a musical note for reception it is therefore only necessary to increase the frequency of the generator.

When this is attempted with the stationary open-spark transmitter, it is found that at about 75 cycles to 150 sparks per second, owing to the conducting ions not having time to disperse from the neighbourhood of the spark gap, the latter is always in a conductive state, and a continuous arcing occurs, which does not allow production of oscillations. Hence with the stationary open gap a musical note cannot be obtained.

With the quenched gap, however, as already explained, the ions are automatically removed and we are able to increase our rate of sparking quite easily to 2000 sparks per second.

Normally Quenched-Spark transmitters are worked by 500 frequency generators, so producing 1000 sparks per second, giving a highly musical note of 1000 vibrations per second at the receiving stations' telephones, this note being easily distinguished from atmospherics, and allowing the range for a given output of energy, owing to superior audibility of note, to be much increased. Constancy in the wavelength of Quenched-Spark radiations permits also of much sharper tuning and better resonance of the receiver. Often in places such as South America, noted for continuously bad atmospherics, wireless communication is only rendered possible by use of a musical note.

A further advantage of the musical note of Quenched-Spark stations is that it enables "jamming" to be eliminated. Jamming is the mutual interference caused when several wireless stations send together on the same wavelength. If jamming occurs with a Quenched-Spark station, it is only necessary to vary the speed of the generator of the station, which produces a different rate of sparks per second, and so *varies the note but not the wavelength at the receiving station*, the operator at which can easily select from the various notes he hears, that of the particular station he wishes to read.

The total energy imparted to a wireless aerial is dependent upon the rate such energy is imparted per second. As we have seen above, owing to arcing there is a limit to the rate of sparking and supply of energy to the aerial with an open-spark gap. In the case of the quenched gap, the only practical limit is due to the frequency of the note of the received signals, rising above the range of audibility of the human ear.

Within such limit the rate at which energy can be imparted electrically is unlimited, and hence with a given aerial and a Quenched-Spark transmitter, much more energy can be imparted to and radiated from the aerial than is the case with an open gap station.

The advantages already enumerated permit, for transmission over a given range, the employment of a much smaller prime power, smaller apparatus and smaller aerial when a quenched gap is used, so giving dependent economical advantages, especially for portable military stations.

This high efficiency of quenched-gap stations led to the first scientific standardisation of commercial wireless stations, most of which, even at the present day, are still specified most unscientifically according to the energy they *consume* instead of that they *radiate*.

With such specification for a 3 kw. open-spark station, the useful radiated energy is only about 25 per cent. or .75 kw. To radiate the same amount of energy, with the Quenched-Spark efficiency of 75 per cent. only 1.0 to 1.5 kw. prime energy is necessary. To the non-technical buyer the 3 kw. station would appear more advantageous, but indeed, the 1.5 kw. is most advantageous since it radiates more energy and offers the additional advantages of freedom from interference by atmospherics and jamming.

Hence the only scientific classification of wireless stations must be upon radiated energy and not consumed energy.

It has been found of recent years that continuous waves can be transmitted much more easily than damped waves, most probably owing to the first few waves suffering attrition of their energy in neutralising the charges of the ions in the air, the rapid passage of succeeding waves allowing the attrition of these waves to be much smaller, since the air has not sufficient time to become again ionised, as is the case for undamped waves of varying energy which occurred with beats.

The radiations of Quenched-Spark stations having low decrement and approximating to continuous waves are therefore less

likely to be subject to such energy attrition than the radiations of open-spark stations.

A resultant economical advantage of the use of the quenched gap is due to its silent working.

With an open gap station to bridge the greater gap distance (2 to 10 inches) a higher voltage must be used and loud tearing disruptive sparks occur. These are so objectionable that the transmitter has to have a specially constructed sound-proof cabin, the walls of which must be insulated against sound by means of cork or sawdust.

To build such a cabin on board ship involves an additional expense of about £200, and increases the room taken up by the installation.

With the quenched gap, the total sparking distance is extremely small (1.6 mm.), a much lower voltage is used, needing less electrical insulation, and there is no objectionable disruptive discharge, but only a slight hissing noise. The necessity of sound insulation is so obviated and a direct saving of about £200 is effected. The room required for the installation is also much smaller, both because a large silence chamber is unnecessary and the apparatus is smaller.

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CHAPTER III.

TRANSMITTING APPARATUS.

THIS chapter will deal with the component parts of the transmitting side of a wireless station. Transmitting apparatus installed for special purposes, but not commonly installed in commercial stations, will be deferred to a later chapter.

Whilst the apparatus described is essentially that of the Quenched-Spark system, most of the remarks are equally applicable to other systems, for example, the differences between the Quenched-Spark leading-in insulator and the Bradfield insulator of the Marconi Company, the Marconi magnetic transmitting key and the Quenched-Spark transmitting relay, are those of details of design only and not of principle.

The most important difference between typical Quenched-Spark and Marconi commercial stations is that of the alternating current source, which in the first case is a motor generator and in the second case a rotary converter.

General Arrangement of Station.—The most important apparatus of a Quenched-Spark transmitter is represented diagrammatically on the opposite page.

The source of energy (in the Quenched-Spark system) is an alternating current generator *A* delivering 500 cycle current. This alternator is usually driven by a motor but is occasionally, in land stations, direct-driven by the prime-mover, i.e. a steam or oil engine. This is not to be desired, since irregularities in the speed of the prime-mover destroy the sine form of the alternating current wave.

Both motor and alternator are controlled by a common switchboard. The alternator circuit is completed through the primary windings E_1 , of a transformer and a choke coil *D*, which is inserted in order to provide the necessary inductance to tune this low-tension circuit to the high-tension circuit, so permitting economic transference of energy to the latter circuit.

The choke coil, by its high inductance, also serves to prevent back surges of high-frequency energy into the alternator windings from the excitation circuit.

Signalling is carried out by interruption of the alternator

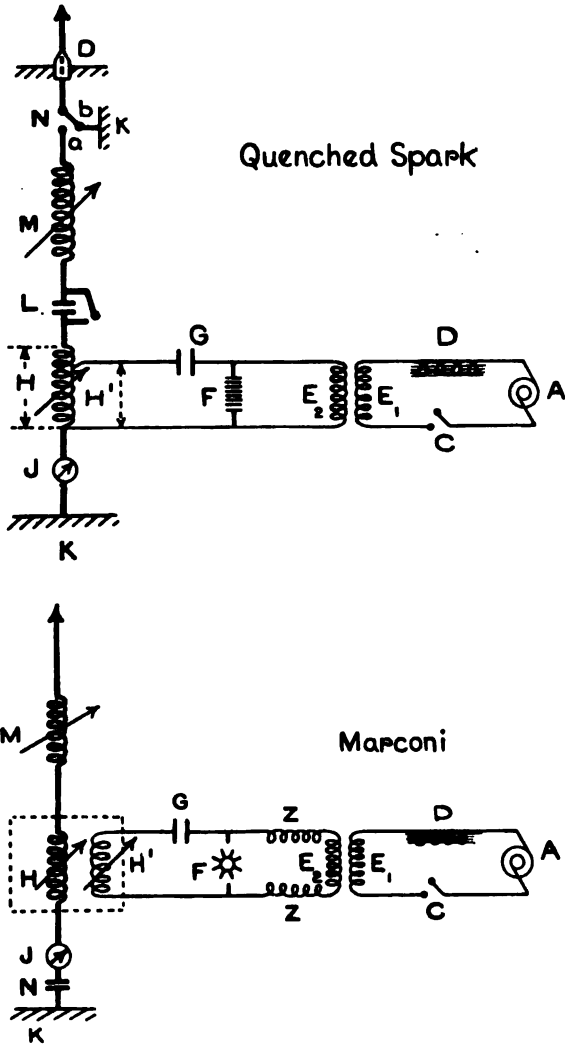


FIG. 20.—Comparison of Quenched-Spark and Marconi circuits.

circuit, by means of a Morse key C for small stations, and by means of a relay, worked by a Morse key, for large stations.

The high-tension circuit, which corresponds to the Marconi

"jigger" circuit, is in Quenched-Spark practice known as the "primary" or "excitation circuit," since oscillations set up in it excite oscillations in the radiating "secondary" or "aerial circuit".

The energy from the winding E_2 of the transformer charges the capacity G of the excitation circuit, this circuit being completed by the excitation and coupling inductance H' . The electro-static and electro-magnetic energy connected with these, when the necessary voltage has been attained, causes the spark gap F to break down. The oscillations, produced in the excitation circuit owing to this breakdown, set up similar oscillations in the aerial circuit. Inductance in this circuit is provided by the coupling inductance H and by a variable inductance or "variometer" M . The current in the aerial, which is earthed at K , is shown by a hot-wire ammeter J . Maximum reading of this instrument indicates the condition of resonance between the excitation and aerial circuits.

When working on low wavelengths a "shortening capacity" L is switched in and serves to decrease the wavelength of the aerial circuit. The switch N is known as a "lightning switch," since when at the position b the aerial, connected through the "leading in insulator" O , is put to earth and damage cannot then be caused to the apparatus, by lightning or other violent electrical discharges. During transmission and reception this switch is in position a and the aerial is then connected to the apparatus.

Having now described the general arrangement of a wireless transmitter, we will consider the characteristics of particular pieces of apparatus.

The Power Circuit.—For the smallest types of station the source of the high-tension current delivered to the excitation circuit is an induction coil, specially wound for heavy current work and designed to work off a direct current supply of 30 to 110 volts.

Such a coil is shown in Fig. 21.

It requires about 350 watts and is fitted with a special heavy hammer-break shunted by a condenser to prevent excessive sparking at the platinum contacts. Occasionally special break devices such as the Wehnelt and the Mercury turbine are used. The most common practical type is the hammer-break. Those requiring details of other special interrupters should consult Fleming, or some book dealing with induction coils.

Such coils are provided with all marine installations, which work off motor generators, in order that, should the latter be put

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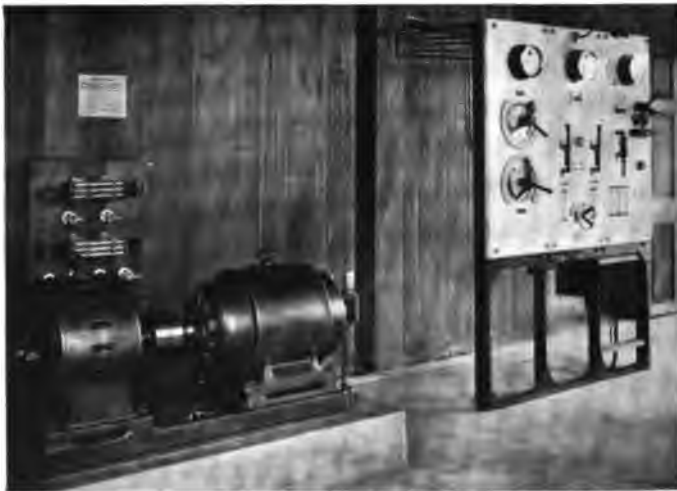
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FIG. 21.—Heavy current induction coil for wireless transmitter.
[See p. 74.]



Alternator. Motor.

FIG. 22.—Low-tension plant.
(Sandakan Wireless Station, British North Borneo.)
[To face p. 75.]

out of action by an accident to the ship's dynamos by wreck, etc., transmission can still take place by means of the induction coil, worked off a battery of accumulators, usually of 32 volts. The provision of such an emergency set with ship installations is, by international law, compulsory for most ships, largely as a result of the "Titanic" catastrophe, which ship appears not to have carried such an emergency set.

Stations radiating more than $\frac{1}{4}$ kw. of energy are fed with high-tension current from a motor alternator of the necessary output.

Such a motor generator and its controlling switchboard are shown in Fig. 22.

The motor is shunt-wound and does not need special description. Upon ships they are usually 65 or 110 volt machines, and for land stations sometimes 220 volts.

The starter and speed regulator are usually installed beneath the switchboard. These are often fitted in a combined form. They are not essentially wireless apparatus, but since a fault in them is extremely difficult to locate, except to those having considerable general electrical engineering experience, the actual circuits are dealt with in detail in Chapter XIV., on "Maintenance of Stations".

Sometimes automatic starters are used, so that the motor can be installed at a distance from the operator and started or stopped at will, from the receiving bench. These are operated by small pushes actuating relays. The motor generator can then be installed at a distance, so ensuring that the noises of the generating plant cannot cause interference during reception. This becomes of importance when the prime-mover is a petrol engine. No such objectionable noise is produced by the comparatively small motor generators used on ships and in small land stations. They are not further described since they are not essentially wireless apparatus and belong to the region of electrical motor design and manufacture.

The instruments upon the switchboard comprise a direct current ammeter for the motor, an alternating current ammeter for the alternator, and a voltmeter. Their connections may be seen in Fig. 42.

With land stations a frequency meter is also usually installed. The common type of such frequency indicators is that of Frahm. This consists of a previously designed range of vibrating steel reeds, each of which is placed before a corresponding small electro-magnet. When the frequency of the current alternation, in the alternator feeding circuit, corresponds to the mechanical vibrating

frequency of any particular steel reed, this is alternately attracted and repulsed. The frequency of such attraction and repulsion corresponding to its mechanical vibratory frequency, resonance occurs, and the reed is set into very violent vibration, by the acting magnetic forces. Since the reeds are very dead beat to any vibration except that of their own natural frequency, only that particular reed of the series vibrates which corresponds to the electrical frequency, and the motion of the reeds is made conspicuous by their being coloured and the frequency marked. With such a frequency indicator it is very interesting to watch consecutive reeds become vibrating and then die out as the speed, and therefore frequency, of the alternator is increased.

The alternator is of the inductor type, which though once used for power work at low frequency, is now very rarely seen. The machines used for wireless work (Quenched-Spark system) have the relatively high normal frequency of 500. The inductor type machine, which has no rotating windings, is particularly suited for this frequency, as rotating windings, relatively difficult to insulate, would be a source of weakness with 500 frequency currents, which tend to break down high insulation rather than pass through inductive windings. As there are few books dealing with the principle of this form of inductor alternator, this will be shortly mentioned.

A laminated rotor is magnetised by the field due to two excitation coils (Fig. 23). This rotor has at each end a number of teeth through which a magnetic circuit is made, via the stator coils and the yoke of the machine, as seen in the top half of figure. One stator coil is acted upon by all the N-pole teeth and the other by the S-pole teeth, and it should be noted that the magnetic flux in either armature is never reversed in direction, but only continually rising and falling.

The stator has twice as many teeth as the rotor and every alternate one is wound, all the windings being in the same direction and connected in series.

The production of alternating current is as follows:—

When a rotor tooth is opposite an unwound stator tooth A, the flux in the adjacent wound tooth is a minimum and practically nil owing to the relatively large air gap between it and the rotor. The change of flux and hence current induced in the stator windings is therefore practically nil, flux and induced current corresponding to positions A on the curves Figs. 24 *a* and *b*.

As the rotor tooth passes from an unwound to a wound tooth the flux in the latter rapidly grows, a maximum change of flux and induced current occurring at some point before B as shown

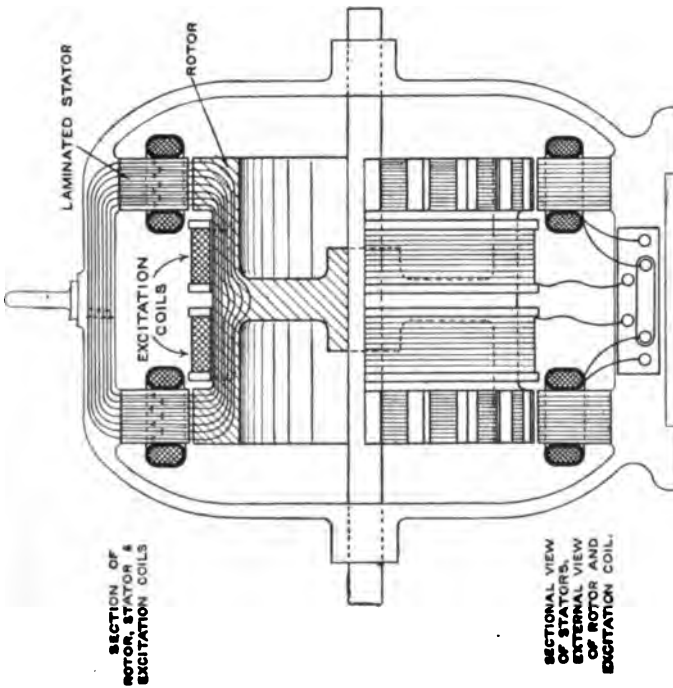
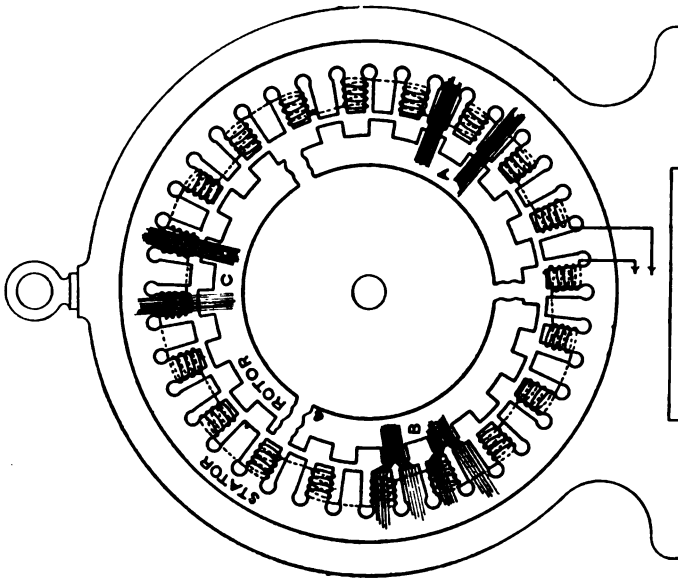
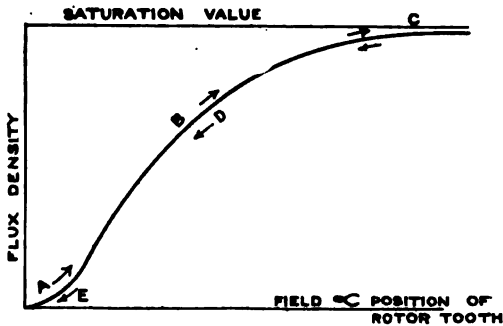
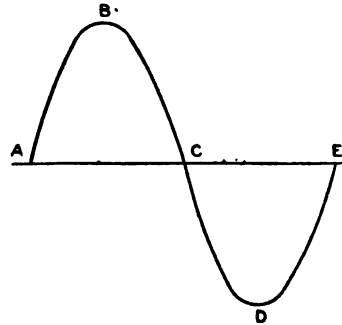


Fig. 23.—500 frequency alternator. (Inductor type.)

by the slope of the curve. When B is reached the wound tooth is nearing saturation and the rate of increase of flux and hence induced current diminishes, until at a point C, when the rotor and wound stator tooth are opposite each other. The latter is then practically saturated, and the change of flux is nil and the induced current is zero, corresponding to C in Figs. 24 *a* and *b*.

The reverse action now takes place, with further movement of the rotor tooth, the flux at first slowly decreases until maximum change of flux and induced current is obtained at (D) and finally a minimum value of flux and current at (E) when the rotor tooth is again opposite an unwound stator tooth. As, however, the flux may be considered during the decrease to leave and not

FIG. 24 *a*.FIG. 24 *b*.

enter the stator, the induced current is in the reverse direction as indicated by the current curve (Fig. 24 *b*).

In order to produce an approximately sine value of the current the spacing of the teeth must be correctly made. The normal machines are designed to give, when the two stator windings are in series, 220 volts and when in parallel, 110 volts. The former voltage is preferably used, since when in parallel the efficiency may be lowered by internal currents, due to slight variations of the stator coils, very difficult to avoid in actual manufacture.

On the larger alternators there are usually 20 rotor teeth and 20 pairs of wound and unwound stator teeth. The speed of revolution being 1500 per minute, i.e. 25 per second, the frequency of the machine at normal speed is $20 \times 25 = 500$ cycles per second. By varying the speed, by means of the motor field regulator, the frequency can be changed between the limits

of 30 per cent. up or down, permitting a change of frequency from 350 to 650 cycles per second.

As the spark gap of the transmitter is broken down at each peak value of the voltage, i.e. twice per cycle, and each breakdown causes the emission of a wave train from the aerial, the number of wave trains emitted can be varied between 700 and 1300 per second. Each train causes the diaphragm of the telephone at a receiving station to give a separate click and the rapid and regular sequence of clicks, gives rise to a musical note the pitch of which will vary between 700 and 1300, the normal note being 1000. The note of the received signal can hence be varied by 250 vibrations a second, or approximately an octave, either above or below the normal note due to 1000 vibrations. This possibility of variation of the note permits several Quenched-Spark stations to work upon the same wavelength at the same time, without mutual interference, if each station uses a different musical note to the others, i.e. runs its alternator at a different speed.

The output of the alternator is varied by alteration of the current in the magnetising coils and therefore the strength of the magnetic field in the rotor teeth.

To prevent excessive noise due to the impact of the air upon the teeth of the rotor, the gaps are often filled with wood or some paramagnetic substance as aluminium, which tends to concentrate the magnetic field to the rotor teeth.

Owing to the machines being immediately thrown when signalling occurs, from no load to full load and vice versa, the motor must be shunt-wound to prevent variation of the speed and therefore of the transmitted signal.

Protection of Windings from High-Frequency Surges.—Such sudden change of load causes energy to surge back from the excitation circuit through the transformer windings. It is a characteristic of high frequency energy, that it will break down very high insulation, rather than pass through highly inductive windings, such as the motor field and alternator windings.

To prevent such breakdown it is necessary to provide some way to prevent such surges from returning to the motor generator.

Use is made of the fact that while a condenser will not permit of the passage of direct and low-frequency current, it offers no obstacle to high-frequency current.

Across the motor field, and the alternator field and stator

circuits of the motor generator a pair of condensers and resistance lamps are connected as follows :—

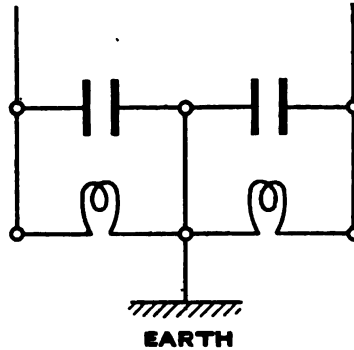


FIG. 25.—Connections of high-frequency device.

Owing to these being in shunt to each particular winding and to their having practically no inductance, the high-frequency surges prefer to pass through these "high-frequency devices" rather than to pass through the highly inductive windings of the motor and alternator. The energy of the surges, on entering these devices, is either consumed as heat by the resistance lamps, or passes to earth through the condenser.

These devices, having high resistance, consume very little of the energy generated by the machine, since the bulk of the relatively low-frequency current passes through the shunted low-resistance windings of the machine and not the high-frequency device.

Such high-frequency devices can be seen upon the wall in Fig. 22. Modern practice omits the resistance lamps and relies upon the condensers only (Fig. 26) since no fear of damage can be caused to the machine by the lamps short-circuiting.

Interruption of Current for Transmission.—To interrupt the low-tension alternating current circuit for signalling purposes an ordinary Post Office Morse key with platinum or tungsten contacts is used for small stations.

With stations radiating more than 1 kw., one or more relays worked by such a key are used, instead of direct interruption by the key, which would be practically impossible owing to sparking and dangerous to the operator.

Such a relay is shown in Fig. 27 *a* and in section in Fig. 27 *b*. It consists of a soft iron yoke in which an armature moves. The

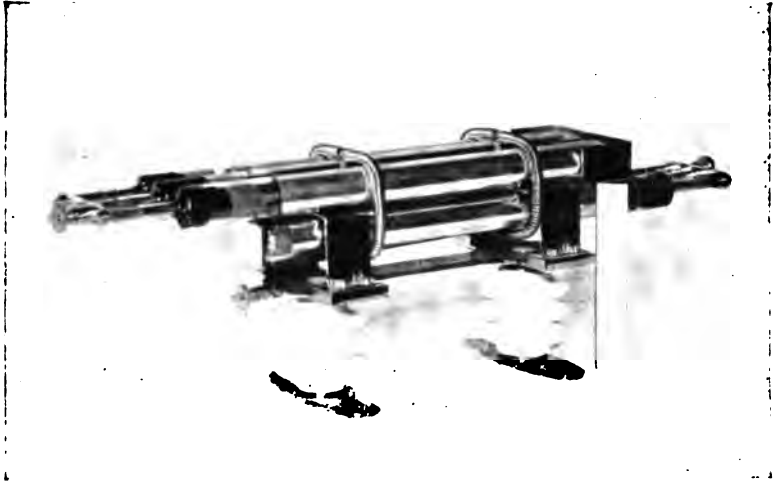


FIG. 26.—High-frequency device (condenser battery).

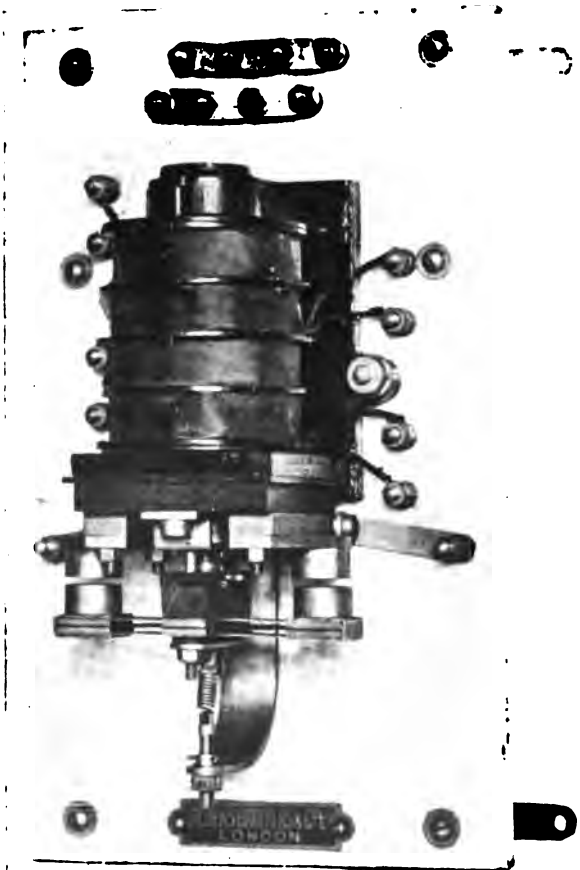


FIG. 27 a.—Transmitting relay.

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yoke is magnetised by four coils which are separately connected to eight terminals at the top of board on which the relay is mounted. By putting these terminals in series, parallel, or series-parallel connection, the relay can be used with various voltages of direct current supply. Passage of current in these coils, magnetises the iron yoke, which then attracts the armature. Beneath the coils and insulated from each other are two large

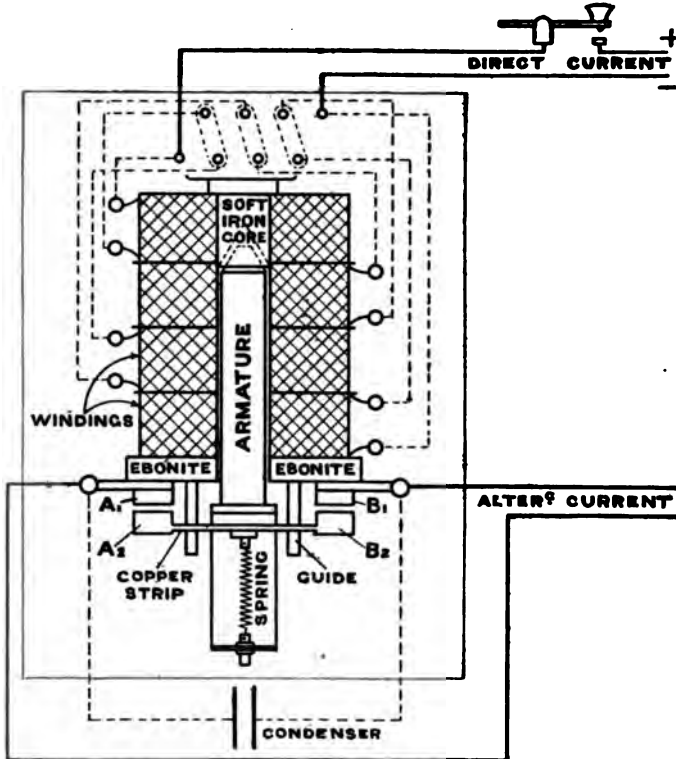


FIG. 27 b.—Transmitting relay.

contacts A_1 and B_1 . If now the direct current circuit is closed by depressing the Morse key, the rise of the armature causes the alternating current circuit to be closed, by the rise of the lower pair of contacts A_2 and B_2 which are in metallic connection. Directly the Morse key is released current ceases to flow in the coils, the yoke becomes demagnetised and the armature falls back owing to its weight, assisted by the spring seen at the bottom of the relay. The alternating current circuit is therefore closed and

opened synchronously with the closing and opening of the Morse key, and the contacts making the circuit, being very substantial, will permit of the safe breaking of a much heavier current than can be done with a simple Morse key.

A condenser is shunted across the relay contacts in order to absorb the energy set free by the breaking of the circuit and so to prevent excessive sparking and injury to the contacts.

In consequence of the constant vibration which the relay undergoes all nuts must be securely pinned. To minimise the vibration the copper strip joining the lower contacts is laminated to give it a certain amount of spring. Guides are provided to keep both pairs of contacts parallel in order that contact of both pairs is made equally at the same instant.

The choke coil and transformer which serve to complete the low-tension alternating circuit do not need detailed description. The former is made step by step in small stations and continuously variable in large stations. As already mentioned it is used to provide the necessary inductance, to tune the low-tension circuit to the high tension excitation circuit, and so cause efficient transference of energy to the latter.

The transformers in stations radiating up to 15 kw. give secondary voltages up to 20,000 volts. Owing to the high-frequency currents, the cores must be very highly laminated to minimise eddy losses.

The insulation must be very good owing to the overloads which occur in the installations. As the insulation can only, for mechanical reasons, be carried to a certain limit in the larger stations, protective inductance coils as shown in Fig. 28 are inserted at each secondary terminal. These have a high inductance, and if a very heavy surge of energy occurs, will break down before the secondary windings of the transformer. They so protect the transformer, the repair of which would entail considerable time and expense whereas a new protective coil can be easily replaced.

In the larger stations it is also the custom to earth one side of the secondary coil through an inductance, so that sparks do not pass owing to a large potential difference between the secondary coil and the iron case.

High-Frequency Resistance.—The coils just described if made of ordinary wire would have a very high resistance, be very inefficient and also cause rapid damping of the oscillations.

The resistance of a wire increases very greatly with increase of the frequency, owing to what is termed the "skin effect," i.e. with the rapid alternation, the current only penetrates to a small



FIG. 28.—Protective inductance coil for transformer windings, etc. [See p. 82.]



FIG. 30 a.—Large oil-condenser dismantled. [See p. 85.]



FIG. 39 a.—Rendahl strain insulator. [See p. 95. To face b. 82.]



distance below the surface of the wire, so that the effective conductor is only provided by the periphery of the wire, and hardly at all by the centre. Hence there is little or no advantage in the use of solid conductors in wireless plant. Metallic tubes are equally efficient, since the resistance is proportional to surface area and not cross section of the conductor. Moreover, they are less expensive.

To minimise such an effect a special wire is used for all high-frequency windings and connections. This wire consists of a large number of separate wires, insulated by enamel and plaited together. The number of separate wires often amounts to 20,000 so that the total periphery of the wires is very much greater than a single wire of equal section to that of all the separate wires.

Often the wires are silver-plated, the layer of silver having a much better conductivity than the outer layer of copper of the wire. Such wires should never be nickel-plated since nickel has a lower conductivity than copper. Nickel-plate in all wireless apparatus is to be generally avoided. Silver-plating is better than bare copper, but often, to preserve copper from oxidation at sea, or in the tropics, when silver would be too expensive, there is no option except to use nickel.

Note on Theoretical and Practical Values of Resistance, Inductance and Capacity.—Owing to the superior demands on his time, by far more important subjects, the mathematical training of an engineer has necessarily to be confined to, usually at the most, a knowledge of the more straightforward differentiations and integrations, and that without any great attention to the theorems of higher pure mathematics upon which many of these operations are based.

The general electrical engineer who has usually dealt with direct current or low-frequency alternating problems and found such a mathematical training amply sufficient, on turning his attention to wireless telegraphy, is confronted and usually astonished by meeting such expressions as:—

1. The resistance of a straight wire of square section (a^2), of specific resistance ρ , permeability μ , direct current resistance R , is, at frequency n , of resistance R^1 given by—

$$\frac{R^1}{R} = 1 + \frac{23\pi^4\mu^2n^2a^4}{45\rho^2} - \frac{3223\pi^6\mu^4n^4a^8}{14175\rho^4} + \dots \text{ nearly!}$$

(Edwards).

2. In high-frequency inductance formulæ he will meet many of which the following is typical:—

$$L = 4\pi a \left\{ \left(1 + \frac{r_1^2 + r_2^2}{8a^2} \right) \log_e \frac{8a}{r_2} - 1.75 + \frac{2r_2^2 + r_1^2}{32a^2} \right. \\ \left. - \frac{r_1^2}{2(r_2^2 - r_1^2)} + \frac{r_1^4}{(r_2^2 - r_1^2)^2} \left(1 + \frac{r_1^2}{8a^2} \right) \log_e \frac{r_2}{r_1} - \frac{r_1^4 + r_1^2 r_2^2 + r_2^4}{48a^2(r_2^2 - r_1^2)} \right\}$$

(Grover)

and similarly for capacities at high frequencies.

The empirical use of such formulæ is scientifically unsound, and if it is wished to discover their origin, he must consult such advanced treatises, as Russell's "Alternating Currents," or more often look up an original paper, perhaps in some foreign journal. In any case the inquirer becomes involved in a mass of higher mathematics, of little interest except to the mathematician, pure and simple.

Should he decide to use such an expression empirically, the next discovery is that the practical requirements of his problem differ to the conditions required by the formulæ, in size, conformation, etc. It requires years of mathematical training to be able to read the origin of such expressions, and as the engineer may be in the wilds of, say, Borneo, with no possibilities of accession to the original paper, their use is absolutely impossible. Moreover, his problem may have to be decided in minutes, instead of weeks.

There is therefore only one rule in making high-frequency calculations, namely, don't do so, unless a simple empirical formula, or a readily derived one, such as $t = 2\pi \sqrt{LC}$ is available.

Practical experience in high-frequency design is the main requirement. With this, the approximate values and suitability of any particular piece of apparatus to its purpose, can be easily judged, and if not, a simple actual measurement will soon decide the question, under the actual conditions, which an empirical formula will never do.

One useful point to remember is the existence of mutual inductance, so that, if coils are wound in sections and each measured, the value of the total on assembly will, by their mutual inductance, be enormously increased.

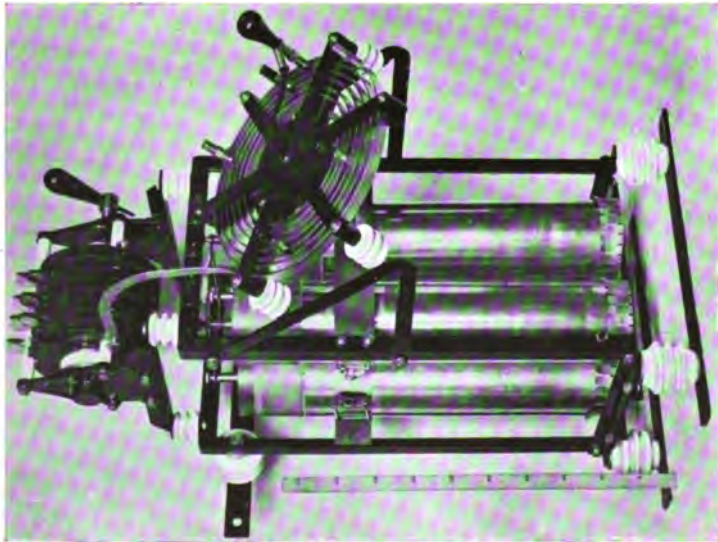
Whilst pointing out that, in practical work, advanced mathematics are not absolutely essential, it must be borne in mind that without more or less mathematical treatment it is questionable whether any deep knowledge of physical phenomena can be thoroughly attained. Whilst mathematical knowledge should be by no means neglected, to the practical engineer experience in detecting faults, in say a combined starter, will be found to be of more practical advantage than De Moivre's theorem.

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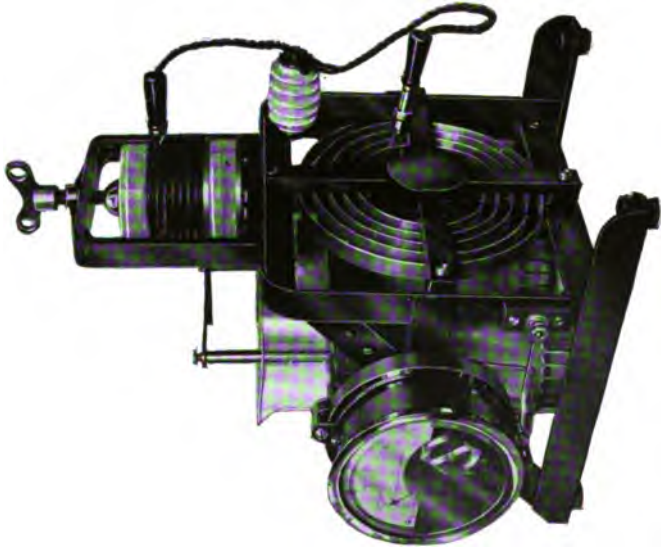
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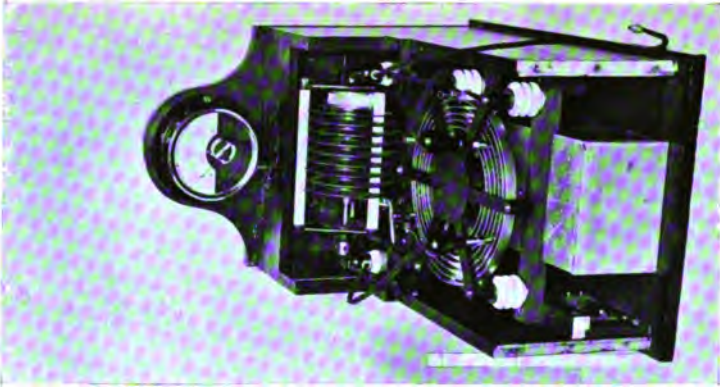
—



a. Large jar type.



b. Small jar type.



c. Box type.

FIG. 29.—Excitation circuits.

[To face p. 85.

The Excitation Circuit.—The excitation circuit consists of a Quenched-Spark gap, condenser, and inductance, the latter serving to couple the aerial circuit.

All stations follow either of two forms shown in Figs. 29 *a*, *b*, and *c*. The first two are known as the “jar type” circuit, since for the condenser a battery of Leyden jars in parallel are used.

The spark gap is mounted on the top of the frame and in front is the excitation and coupling inductance. Tappings for various wavelengths are taken on this inductance by means of plugs and sockets.

The third apparatus is known as a “box” type circuit, since the apparatus is all contained in a wooden box. The condenser seen below the horizontal inductance coil is a paper condenser formed by interleaving tinfoil and paraffined paper. As with this type of circuit no variation of inductance is provided in the aerial for tuning purposes, a sliding inductance is placed at the left-hand side of the box. The aerial hot-wire ammeter is fixed to the back of the case in this type of circuit.

In addition to paper and Leyden jar condensers, oil condensers are also used, each particular form having special advantages for particular purposes.

The oil condenser is made of strips of tinfoil between glass-plate dielectrics, immersed in paraffin oil, contained in an iron case seen in Fig. 30 *a*. The iron case containing this condenser protects it from breakage, but is apt to leak and cause dirtiness.

The most serious disadvantage is that should the dielectric break down, some considerable time is needed to unbolt the case to replace or repair the damaged part. Again in high-power transmitters, on breakdown, the oil is rapidly decomposed by the heat of the spark which then occurs, hydrocarbon gases are so evolved and, with large stations, may be so rapidly formed as to exert an explosive force, an actual occurrence experienced by the writer.

To prevent such breakdown owing to excessive voltage, a safety spark gap is provided consisting of two carbon electrodes, each connected to one set of the tinfoil plates. The distance apart of the electrodes is such that a discharge will pass between them before rupture to the dielectric can take place. Devitrification of the glass may cause breakdown after long use.

Paraffined paper condensers are largely used for portable stations, since they are free from danger of mechanical breakage, have no oil to leak, and occupy little space. Should they break down, however, it is usually more advantageous to completely replace them than to repair them.

The Leyden jar form is likely to meet with objection from those familiar with other branches of engineering, owing to their fragile laboratory appearance. They are, however, for many purposes, the best type, being light and capable of standing heavy overloads. They are rarely broken, and in such cases any jar may be replaced by another in a few seconds, an advantage over the paper and oil types. The choice of a glass, of suitable dielectric properties, is an important requirement. Standard Quenched-Spark Leyden jars, with their relative sizes and dimensions, are shown in Fig. 30 *b*. One of the best designed forms of Leyden jar capacity is that of Mosicki

The condenser battery is often arranged so that a large change

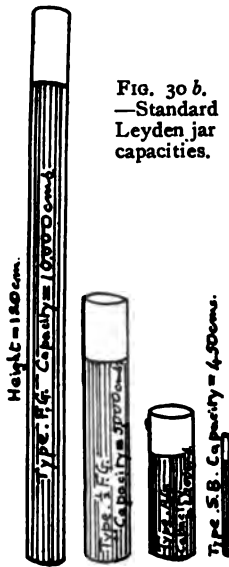


FIG. 30 *b*.
—Standard
Leyden jar
capacities.

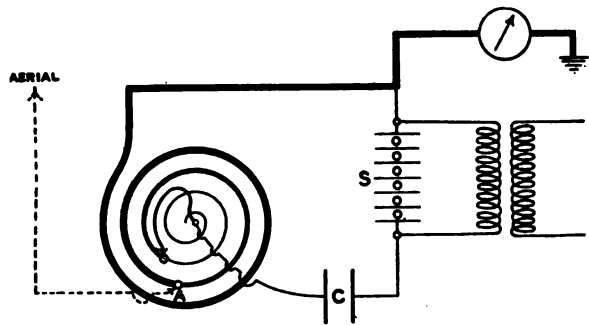


FIG. 31.—Direct coupling of a Quenched-Spark set.

of wavelength can be obtained, by changing with a switch the arrangement of the units from parallel to series, etc., so giving a very different total capacity.

One of the most difficult things to understand practically in a Quenched-Spark station is the method of coupling the excitation and aerial circuits of such an installation. This can be seen by aid of the above diagram, Fig. 31.

The excitation circuit consists of the spark gap S and condenser C, connected, through the centre of the inductance frame, to the inductance by means of a plug. The circuit is completed, through all the heavily marked parts of the inductance to the spark gap.

The aerial is joined to the plug at A and is completed through the most heavily marked portion of the inductance to the spark gap and then to earth through the aerial ammeter.

The common or coupling inductance is the part marked most heavily. This coupling is normally 18 per cent. as defined by Chapter II. Since for the production of the correct wavelength it is necessary for each plug to be placed in its own socket, they are made of different diameter and painted a different colour. Should they be interchanged, the wavelengths of the excitation and aerial circuits, which should be both the same, are made to differ by twice the inductance due to the length of coil marked mediumly heavy.

Several wavelengths can be obtained upon the same coil, by use of further pairs of plugs and sockets, which carry labels indicating the particular wavelength.

In the case of stations above 15 kw., direct coupling cannot usually be efficiently obtained and two flat helices are used, each carrying tappings which induce upon each other. Variation of the fixed wavelengths is then obtained by means of a hand-wheel, which connects the appropriate tappings, whilst variation of coupling is obtained by a separate handwheel, which brings the two coils nearer or vice versa. (See Chap. X., Land Stations.)

For the various other methods in which wireless aerial and excitation circuit may theoretically be coupled, Eccles (p. 89) should be consulted.

When a continuous variation of wavelength is required, for military or naval transmitters, in addition to the coupling inductance a variable or "variometer" inductance is also inserted in the excitation circuit and another in the aerial circuit. One form consists of flat coils of many stranded wires, an even number of which are fixed and have the wires wound in one direction and the odd number of intermediate moving coils are wound in the reverse direction. If the latter are moved within the fixed coils by means of a handle (see A, Fig. 126, p. 254) the mutual inductance is greatly varied. The wavelength for each position of the movable coils must be determined by means of the wavemeter, and plotted against a scale of degrees seen at the side. Usually as a fine adjustment one coil can be varied separately. A screw serves to lock the coils in any position during transmission.

Another form of excitation inductance is also shown in Fig. 126, p. 254. Here the inductance coil B takes the form of a long helix, along which a moving contact is made to slide by rotation of the helix about its longest axis. The wavelength is indicated, after calibration, by means of a marked strip at the top along which a pointer from the moving contact passes. A locking mechanism is provided on the moving contact. A further form of variable inductance is described on p. 251.

The Aerial Circuit.—In the design of the excitation circuit, there is full choice to vary the inductance or capacity to give any desired wavelength according to the approximate formula

$$\lambda = 2\pi\sqrt{LC}.$$

With the aerial circuit, however, which must have a natural period practically equal to that of the excitation circuit, there is less freedom in the design, since the natural period is determined by the length of the aerial wires, their mutual inductance, in the case of ships' installations, with the rigging, funnels, etc., and by other factors. The importance of such mutual inductance is shown by the fact that a ship "tuned" in dock may show a variation of several amperes aerial current when at sea, owing to the mutual inductance due to the surroundings whilst in dock.

It would of course be possible to design an aerial, taking into account the most important of these factors, but it is more economical to standardise the apparatus, and since more than one wavelength is usually desired, some means must be sought by which the wavelength of the average aerial can be made equal to the standard wavelengths used, and for which the excitation circuit is calibrated.

This may be done by variation of the capacity or inductance. Only the latter method is practical to increase the natural wavelength, whereas change of the former *to series* is used to *decrease* the natural wavelength.

For this reason inductance coils in the aerial are known as "lengthening coils" and capacities as "shortening capacities".

Lengthening coils take various forms similar to those used for the excitation circuit.

The simplest form (Fig. 32 *a*), used with the "box" type station, consists of several flat helices enclosed in a wooden case through which plug sockets project for various previously determined wavelengths. Sockets for the aerial are provided so that more or less of the inductance coils may be inserted as required.

The most common form for ships' stations is the "variometer" type shown in Fig. 32 *b*, which consists of two outer fixed coils and one movable centre coil. The two outer coils are wound in opposite directions so that movement of the centre coil varies the inductance between that due to—

1. Two coils closely coupled with current flowing in the same direction and one coil loosely coupled with current flowing in the reverse direction ; or

2. Two close coupled coils having current flowing in op-



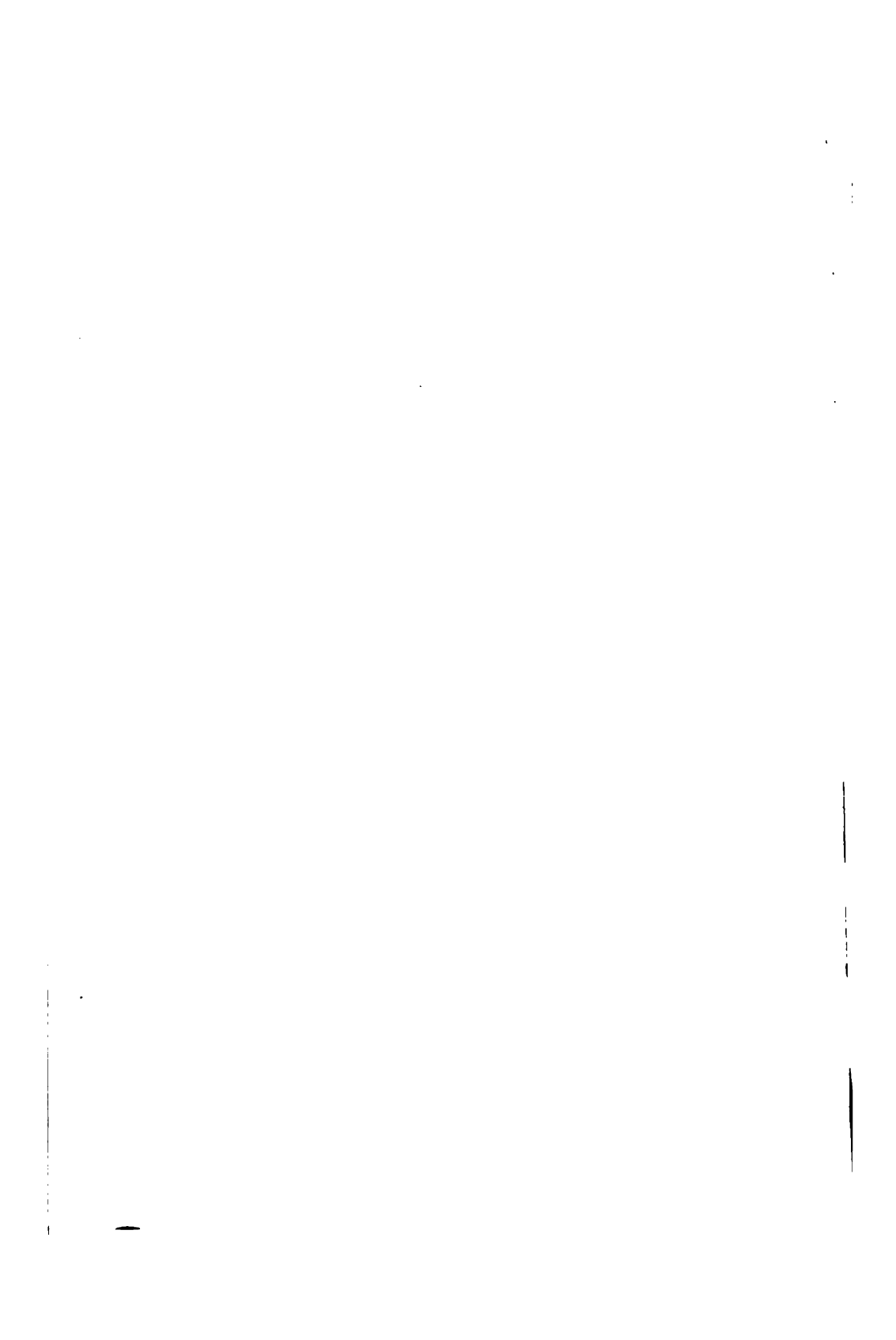
a. Box type.



b. Variometer type.

FIG. 32.—Aerial lengthening coils.

[To face p. 88.]



posite directions and therefore cancelling their separate effects, leaving practically only the inductance due to the other fixed coil.

Another common form of aerial inductance has a number of coils, some of which move along the common axis. Such is the form of the aerial inductance used for land stations in which there is one set of three or more fixed coils and one set of moving coils which are moved vertically by means of a hand wheel and balance weights, and are described in a later chapter on Land Stations (Fig. 142 *b*).

With variometer lengthening coils, the excitation circuit adjustment is first made for the particular wavelength and the aerial inductance is then varied until maximum current is obtained in the aerial by the hot-wire aerial ammeter. The position of this inductance is between the aerial coupling coil and aerial proper. Lengthening cannot be carried out, except with great loss of energy, beyond 40 to 50 per cent. of the natural wavelength of the aerial.

To shorten an aerial, a capacity is inserted in series, since capacities in series give a total capacity equal to the reciprocals of the separate capacities, i.e. $\left(\frac{1}{C} = \frac{1}{c_1} + \frac{1}{c_2} + \text{etc.}\right)$, C being therefore necessarily smaller, λ is also smaller since $\frac{1}{\lambda} = 2\pi\sqrt{LC}$ and $n\lambda = \text{a constant}$.

The effect of this can be better shown graphically :—

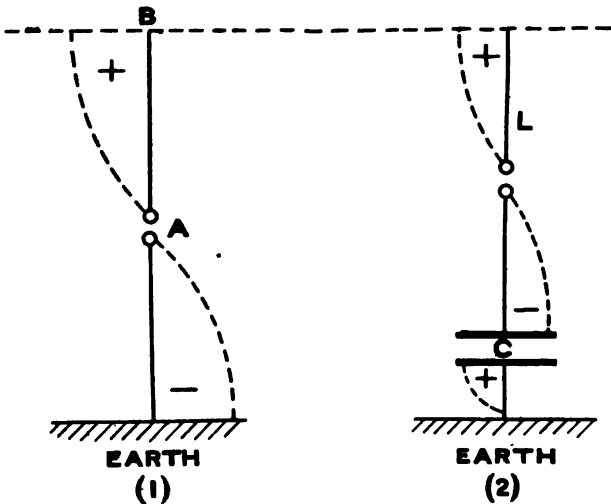


FIG. 33.—Effect of shortening capacity.

If in Fig. 33 (1) the potential at various points in the aerial is set off horizontally, this must be zero at the spark gap and greatest at the end of the aerial. This is the form for a simple aerial, the distance between A and B being half the natural wavelength.

If now a capacity is introduced as at C, the points of potential will be as shown in (2), i.e. the point of no potential being moved further up the aerial and giving a smaller wavelength, i.e. as though the spark gap were actually moved up, the aerial making the distance AB and therefore the wavelength smaller. Hence by increasing the capacity C the wavelength becomes smaller and smaller, giving the desired effect.

Shortening an aerial cannot be advantageously carried out beyond 15 to 20 per cent. of the natural wavelength, and even then the loss of energy is very great, and the aerial ammeter reading is greatly decreased.

Since, however, international regulations specify 300 and 600 metre waves for commercial ship work, and a few land stations transmit on 300 metres, a shortening capacity is fitted in ships' stations, although rarely used, because of lowered efficiency.

A shortening capacity formed by a Leyden jar battery is shown in Fig. 34 *a*. When working on long wavelengths for which it is not required, it is short-circuited by means of a metal clip, seen at the top.

A more simple form is shown in Fig. 34 *b*, where the short-circuiting clip is more distinctly seen.

Instruments for High-Frequency Measurements.—Good tuning of the aerial to the excitation circuit results in the transference of maximum energy to the former circuit. Since the primary circuit pressure is constant, a measure of the current in the aerial is therefore a measure of good tuning and resultant efficiency, and the insertion of a suitable hot-wire ammeter serves to indicate such resonance.

This method of control of tuning was introduced into wireless technology very early by the Telefunken Company.

For the purpose of measuring the current in the aerial, an ordinary ammeter is useless, since these are usually provided with shunts which with low-frequency current diverts a specifically known proportion of the current from the ammeter. With high-frequency current, however, the proportion of the total current which passes through the ammeter differs with the frequency and wavelength, so that an instrument, calibrated for work on one wavelength, will often give an error of 50 per cent. on some other wavelength, owing to the resultant change of frequency.



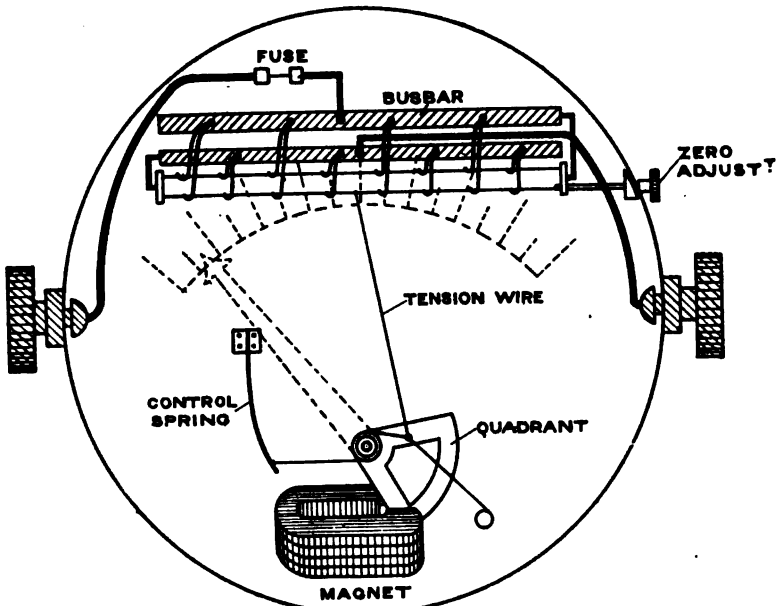
a. Multiple jar type.



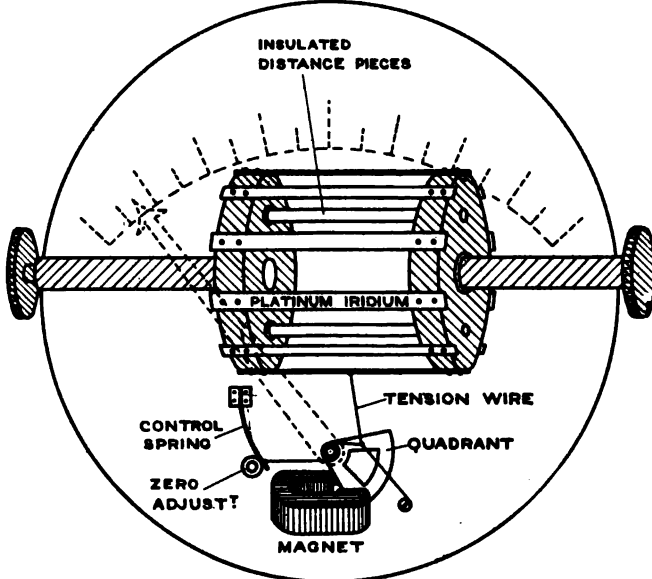
b. Single jar type.

FIG. 34.—Shortening capacities.





a. Bus-bar type.



b. Drum type.

FIG. 35.—Aerial hot-wire ammeters.

Hot-wire ammeters are always used in practice for measurement of aerial currents. For such instruments a shunt need not be used if the expansion wire is sufficiently stout. In such a case, however, the wire does not heat quickly and the reading requires an appreciable time to obtain its maximum, greater than is afforded when sending Morse signals.

In order to obtain an immediate reading with a hot-wire instrument, a special form must be used such as shown in Figs. 35 *a* and *b*.

Dealing with the first, two expansion wires carry equal current but only one is used for indicating purposes. Each section of these two wires does not carry the total current, but only a small proportion of the total passing through the instrument.

This is obtained by the following arrangement, Fig. 36, in which only one wire will be first considered:—

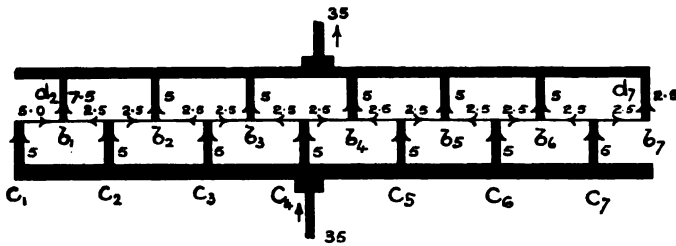


FIG. 36.

A current fed to the heavy lower bus-bar of the instrument is, if the bus-bar has negligible resistance, caused to divide equally into seven smaller and equal currents passing through the strips C_1 to C_7 .

Each current divides on reaching the expanding wire and flows to the other bus-bar through the strips b_1 to b_7 , which all carry equal current (if we neglect for the moment the effect at the ends).

Hence a current of say 35 amperes would divide into seven currents C_1 to C_7 , each of 5 amperes. The heat developed being proportional to the square of the current, the heat in each portion of the expanding wire is approximately proportional to 5^2 and for all the wire to $5^2 \times 7 = 175$. If the total current was passing right through the hot wire the heat would be proportional to $35^2 = 1225$.

With an ammeter on the above principle the heat effect is therefore only one-seventh, and the expanding wire need be of

only one-seventh the cross section of a single conductor. It is therefore much more susceptible to heat changes and will almost give an immediate reading, particularly if more strips are used, as occurs in practice. By this method therefore a very sensitive shuntless hot-wire ammeter is obtained.

We have up to the present assumed that equal current passes through all the strips, but this is not the case. A current of 35 amperes would divide up approximately as shown by the numbers in Fig. 36, and one end conductor d_7 would carry one-half and the other end conductor d_2 one and a half times the average current, causing unequal expansion along the total length of the wire.

To overcome this objection the two expansion wires are used as seen in the actual connections (Fig. 37). This introduces a

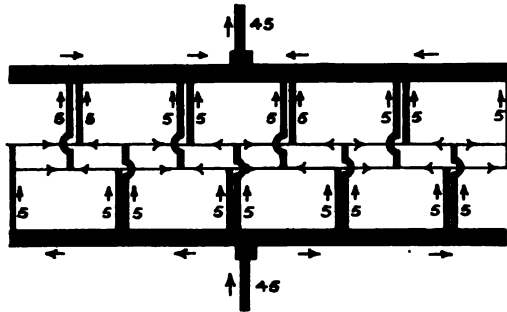


FIG. 37. .

second grid of wires, but in a reversed direction, so that at each end one large current and one small current compensate, and gives the average current in the outer strips also, the effect being virtually the same as if all the strips were placed around a drum. The heating of the expanding wire causes the tension wire to slacken. This in turn slackens a wire passing round a small pulley, which rotates, until the tension of the wire again equals that of the spring controlling the movement. Movement of the pulley is shown by a pointer working over a scale calibrated in amperes.

In order to damp quickly the movement of the pointer a small aluminium quadrant is fixed to the pulley axle, and this, moving in the field of a magnet, has eddy currents set up in it, these currents dissipating the energy and quickly damping the instrument. A tension screw is fitted to alter the tension of the

expanding wires in order to bring the pointer back to zero if a permanent set occurs in the wires.

A simpler drum form of instrument is that shown in Fig. 35 *b*. Here the current divides up and passes through a number of strip conductors held by a frame. These are all exactly equal so that variation of the shunt ratio, due to change of frequency, acts equally in every strip. The expansion of the lower wire causes it to sag slightly and the movement is recorded by an indicating and damping device such as already described.

In both types of instrument the indicating mechanism is insulated, and since no current passes through the pulley wire, no disturbances of the resistance ratios can occur.

Protection against Lightning.—Since such delicate instruments and other parts of the wireless apparatus would be damaged by the passage of a very heavy current resulting from the aerial being struck by a lightning or atmospheric electrical discharge, it is necessary to provide a means of protection for the apparatus from such danger.

This is done by putting the aerial directly to earth during electrical storms, when telegraphic communication is impossible and the station is not working.

For this purpose a "lightning switch or arrester" is used, as illustrated in Fig. 38 A. When the station is working, the switch is open and the oscillatory currents can pass through the upper insulated bar from the apparatus to the aerial, or vice versa. When the station is not working, the switch is closed and all currents in the aerial are led through the switch to earth, so preventing damage to the apparatus. A variable spark gap is present, and this is set and fixed by a responsible engineer in order to prevent, during transmission, over-charging of the aerial, and consequent damage to the apparatus, since before this can occur, a spark jumps across the gap to earth.

A smaller form of "lightning arrester" is shown in Fig. 38 B. This also has a spark gap and the aerial can be put to earth or the apparatus by inserting the plug on the flexible lead in either of two sockets, one above insulating the aerial, and one below putting it to earth.

Insulation of the Aerial.—The aerial, which will be described in detail in later chapters, has to be insulated from all earth connections. For this purpose various insulators are used, the most important being shown in Fig. 39.

Numbers 1 to 4 and 12 are "strain-insulators" used for insulating the stays of the aerial and towers. The insulators most

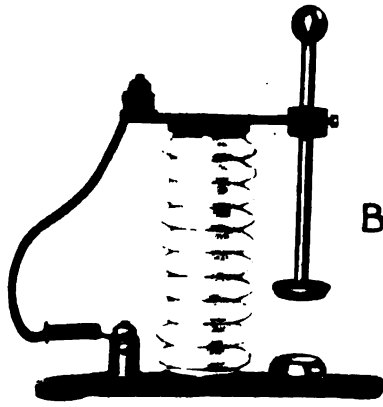
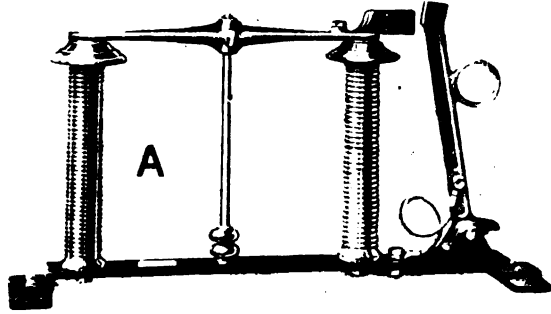


FIG. 38.—Lightning switches.

[To face p. 94-



1
 2
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 11



Fig. 39.—Aerial insulators.

[See p. 94.



Fig. 40 a.—Leading-in insulator.

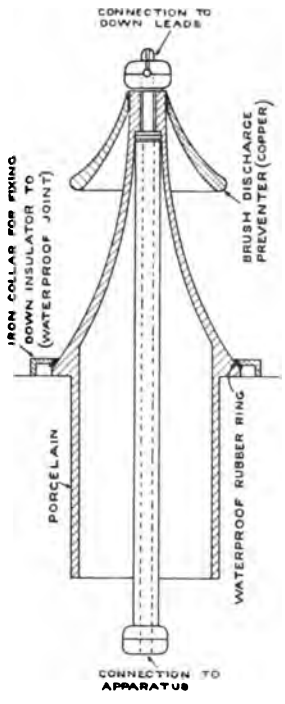


Fig. 40 b.

[See p. 95.

commonly used for this purpose are Numbers 4 and 12. The former consists of hemp rope covered with india-rubber to prevent the hemp, which is a good insulator when dry, from becoming damp. For ship work this insulator has not a long life since the fumes from the funnels cause the rubber covering to decay and the hemp rope is then liable to become wet, and a conductor.

The latter insulator is known as a "chain of egg insulators" since it consists of a chain of five or more egg-like insulators. The special feature of these insulators is that they are so threaded on the iron rope that the porcelain is in compression and not strain, and no danger of fracture occurs. Whilst having better insulation properties, they are easily broken by fall, should the aerial be carried away, which is not the case with the hemp insulator.

Numbers 5 and 6 and Fig. 39 *a* (Rendahl insulator) consist of a cow-hide rope covered by porcelain and protected from rain by the bell-shaped cover, which, in order to prevent brush discharge, has no sharp edges.

Numbers 7 to 10 are insulators used to pass high-tension wires through the walls of a room, Number 9 being also used to insulate the aerial from the hull upon submarines.

An important type of insulator is Number 10, this being used in all stations for leading through the aerial to the apparatus room.

It consists of a large porcelain tube, Fig. 40 *a* and *b*, in which a metal bar is carried, the lower end being connected to the apparatus and the upper end to the aerial. A porcelain jacket surrounds this tube, and a shoulder upon this is fixed to the wall or deck, a watertight joint being obtained by means of rubber washers.

A metallic plug, seen in Fig. 40 *b*, serves to put the aerial to earth, if no lightning arrester is present. A smooth surfaced metallic cap at the upper end prevents brush discharge and damping of the insulator by rain. Since damp is deleterious it is necessary to keep the insulator clean, or electrical leakage will occur by conduction along water collected by surface tension effect of the dirt particles. For this purpose the whole insulator can be taken to pieces by unscrewing the metal cap at the top.

The Complete Station.—A complete installation for marine work is shown in Figs. 41 and 42. The connections are shown below, the figures of particular parts of the apparatus corresponding and being as follows :—

- | | | | | |
|---|---|------------------------------|---|---------------------|
| 1. D.C. fuses. | } | Mounted upon
switchboard. | | |
| 2. " switch. | | | | |
| 3. " voltmeter. | | | | |
| 4. " ammeter. | | | | |
| 10. A.C. fuses. | | | | |
| 11. " switch. | | | | |
| 12. " voltmeter. | | | | |
| 13. " ammeter. | | | | |
| 24. Cut-out for battery charging. | | | | |
| 27. Battery circuit fuses. | | | | |
| 28. Switch for charging emergency battery. | | | | |
| 5. Starter for motor. | | | } | Excitation circuit. |
| 6. Motor. | | | | |
| 7. Speed regulator for motor. | | | | |
| 8. Alternator. | | | | |
| 9. Field regulator for alternator. | | | | |
| 9a. Fine adjustment field regulator for alternator. | | | | |
| 14. Protective high-frequency devices. | | | | |
| 15. Excitation inductance. | | | | |
| 16. " capacities. | | | | |
| 17. Quenched-Spark gap. | | | | |
| 18. Aerial hot-wire ammeter. | } | Emergency transmitter. | | |
| 19. " lengthening variometer. | | | | |
| 20. " shortening capacity. | | | | |
| 21. " lightning switch. | | | | |
| 22. Leading-in insulator. | | | | |
| 23. Receiver. | | | | |
| 25. Charging resistance for battery. | | | | |
| 26. Batteries for emergency transmission. | } | Accessories. | | |
| 29. Resistance to regulate voltage to induction coil. | | | | |
| 30. Induction coil. | | | | |
| 31. Switch to change from main to emergency set. | | | | |
| 32. Morse keys for main and emergency sets. | } | | | |
| 33. Buzzer. | | | | |
| 34. Aperiodic circuit. | | | | |
| Transformer (not seen in photograph). | | | | |

DIFFERENCES BETWEEN QUENCHED-SPARK AND MARCONI STATIONS.

The foregoing description comprises all the essential apparatus of a small power wireless station, such as fitted on ships.

The particular design of the various pieces of apparatus varies with the particular system, and it would exceed the scope of this book to deal with the differences in design of the apparatus of the various companies. Those desiring such detailed descriptions must be referred to articles which appear from time to time in the "Electrician," etc. For the Marconi apparatus, there is no better book than that written by Hawkhead, for the use of Marconi-operators.

The only other small installations (ship installations) of any importance in England are those of the Marconi Company, and the modifications may be summarised as follows :—



FIG. 41.—Quench-Spark station on the S.S. "Chindwin" (the Henderson Line L^{td}.).
[To face p. 96.]

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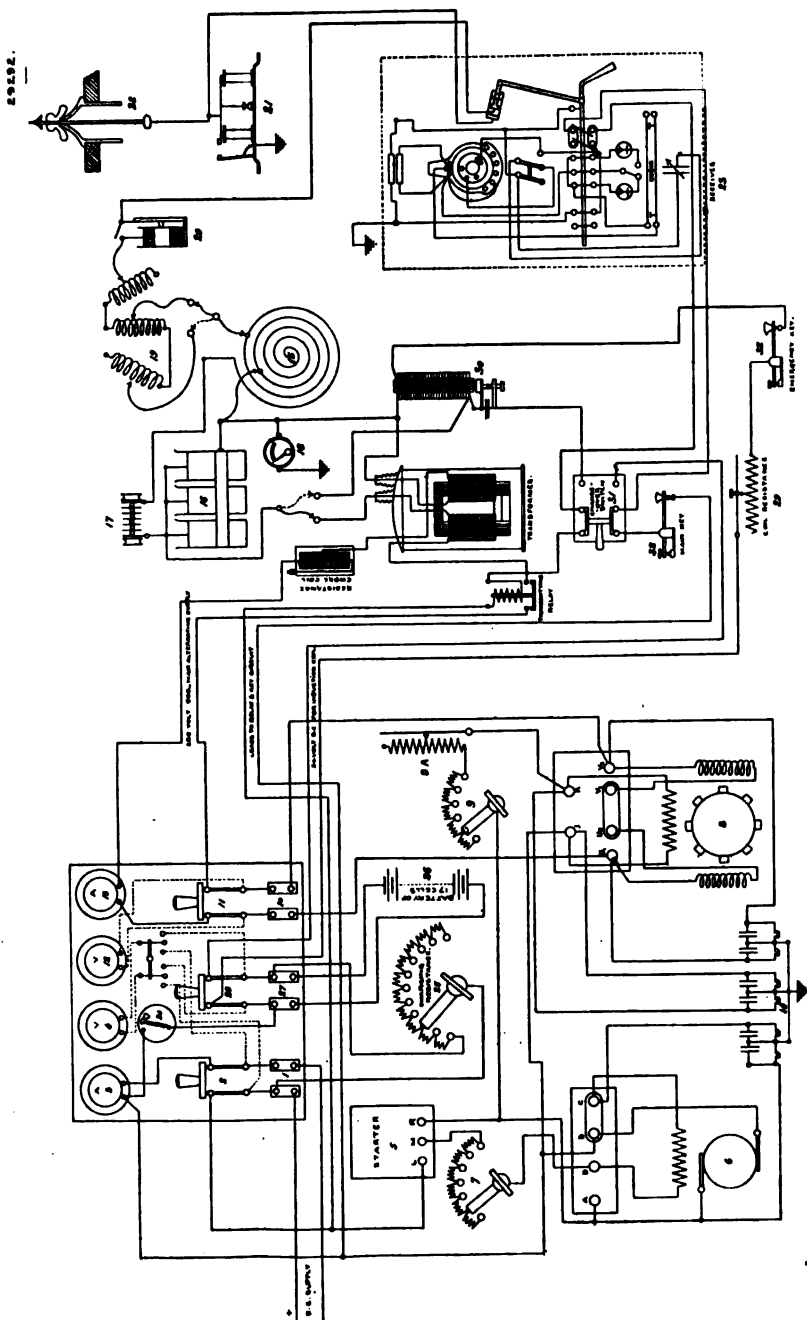


FIG. 42.—Connections of station on S.S. "Chindwin".

General Arrangement of Station.—In Fig. 20 a comparison of Quenched-Spark and Marconi transmitter circuits was given.

The main points of difference are :—

1. The insertion of the protective air-choke coils Z in the secondary circuit of the transformer.
2. The presence of the magnetic coupling HH' (or jigger) between excitation and aerial circuits in place of the auto-coupling.
3. The presence of the "earth arrester" N .

The arrangement given above is stated to be for "Marconi's Syntonic Wireless Telegraphy".

Syntony is a word of Greek origin, once very much used in wireless technology, and is the equivalent of "tuned". As all modern transmitters of any manufacture (including the Quenched-Spark) are nowadays dependent upon tuning, this term conveys no meaning and is best avoided, the term "syntonic wireless telegraphy" being merely an over-elaboration of terms.

The Power Circuit.—Instead of a 500 frequency motor alternator, of the inductor type, a small rotary converter (300 cycles) is used. With such a machine instead of two separate components, i.e. motor and alternator, the motor and alternator windings are wound on a common rotor. As an advantage of this the machine is reduced in size, as a disadvantage such an arrangement does not permit of such high insulation of the windings, which are therefore (at this frequency) more prone to break down. The question of repair, should this occur, is more serious than with a machine having separate components.

Protective Devices for the Generator Windings.—Instead of capacity high-frequency devices, resistance lamps of a long cylindrical shape are used. These are known as "guard lamps".

The Transmitting Key (C).—As with Quenched-Spark stations, all installations, other than the smallest, have a transmitting relay, actuated by a Morse key. The Marconi relay is due to their engineer, Mr. A. Gray, and is known as the "magnetic key". The type of relay already described (p. 80) is equally magnetic, and as it would be practically impossible to use other than a magnetic relay, the term magnetic is superfluous.

The Air-Choke Coils (R).—These correspond to the coils illustrated in Fig. 28. They would appear to be always used for the Marconi stations. In Quenched-Spark practice, except for the largest land stations, they are rarely used, since, as the result of quenching (by the use of the Quenched Gap), back surges of energy are largely avoided, if at all present, because

after the spark discharge, the excitation circuit is broken by immediate loss of conductivity of the gap.

The Spark Gap (F).—This has been dealt with at length in Chapter II. Of recent years, in response to a demand for a musical note transmitter, it has become a practice to install rotary spark gaps (disc discharger).

As mentioned on p. 65, this does not get over the objectionable amount of noise during sparking, and a silence chamber is still necessary. The intensity of this noise shows that sparks of comparatively long length occur, and it is very different to the faint "zizzle" of the quenched gap.

Some of the more early installed ship stations still have open-spark gaps. This is enclosed in a box to deaden the very great sound. The box contains an alkali, as lime, to absorb the oxides of nitrogen formed during the discharge, and so to prevent the corrosion of metallic portions of a gap. A window is usually fitted into the box in order to provide a view of the spark. In common with all electrical discharges, a continual vision of such sparks, rich in red rays, is to be avoided, as it causes dangerous physiological changes in the retina of the eye.

The Coupling.—This is known as the "jigger," i.e. it is an ordinary air transformer.

As already mentioned in Chapter II. the use of the Quenched-Spark permits of the use of an auto-coupling, giving a larger transformer energy ratio without fear of obtaining a dual wave.

The Aerial Circuit.—The Earth Arrester (N).—This consists of two circular plates slightly separated and insulated by mica or ebonite. With any heavy atmospheric discharge, or during transmission, the potential across the gap is sufficient to render it conducting, whereas during reception it is not conductive, and the received oscillations must therefore pass through the receiver parallel to the arrester gap. During transmission, however, it must, by its resistance, cause a great damping of the aerial oscillations.

It would appear that it is not relied upon to absolutely protect the more delicate receiver circuits against heavy discharges, since a switch is usually provided to cut this out of circuit during transmission, a practice always followed with the Quenched-Spark receiver to be described, which is also fitted with arresters of this type, but having a spark gap in rarified gas instead of air.

Indication of Tuning.—This is obtained by means of a hot-wire aerial ammeter, but also, often by noting the intensity of luminosity of an electric lamp inserted in the aerial. This lamp

is much cheaper than an ammeter, but gives a qualitative rather than a quantitative reading.

General Design of Wireless Apparatus.—The general design of wireless apparatus may be described as being "open" or "enclosed". Both methods have advantages and disadvantages.

With the enclosed type of apparatus, where the various conductors are enclosed in a wooden or ebonite box, the apparatus is not so readily interfered with by unauthorised persons and is therefore "foolproof". It is also more protected from accidental injury, and somewhat, in the case of ship stations, from the deleterious effects of salt air.

From the selling point of view, apparatus enclosed in a nicely polished box, plentifully labelled with super technical terms, fosters the mystery element which has become ingrained in wireless engineering, and therefore a very high price can be obtained for what may be merely an ordinary helix of copper strip, or such similar simple apparatus.

As disadvantages to the enclosed type of apparatus we have that in case of breakdown it is not so readily accessible for repair. Many people, including the author, prefer to have as much apparatus as possible open to view. This allows any slight sparking to be seen and immediately attended to, so that a fault does not lie hidden, until all the insulation is destroyed and a serious breakdown results. With open apparatus there is also the satisfaction, in any case of doubt, of being able to trace easily all the various connections.

From the selling point of view, open apparatus does not foster the mysterious element. This is, however, not of great importance when the apparatus is based upon strict scientific principles. Most purchasers, such as the marine superintendents of shipping companies, are men of intelligence, and even if they have very little technical knowledge, are more likely to be impressed by a straightforward experiment (such as the alternate insertion of an open and Quenched-Spark Gap and noting the large increase of aerial current and absence of noise with the latter), than by any attempt to impress them with the mystery of wireless telegraphy.

CHAPTER IV.

RECEIVING APPARATUS.

General Arrangement of Receiving Apparatus.—Wireless reception can easily be carried out on a plain aerial, i.e. one with aerial, inductance, capacity, detector, and earth all in series.

As, however, the resistance of the detector is high, usually several thousand ohms, the presence of the detector in the aerial tends to give the oscillatory aerial circuit a very large damping coefficient, and the oscillations therefore become dead beat and rapidly die out.

This disadvantage is avoided by placing the high-resistance detector in a separate or "detector circuit," directly or inductively coupled to the aerial circuit. With such an arrangement the aerial circuit resistance can be kept very low and it is free to oscillate. Also the detector circuit can be made at will more selective by variation of its coupling with the aerial circuit, so that either, with tight coupling, a large transfer of energy over a large wave range occurs, or, with loose coupling, a smaller transfer of energy occurs, with a very small wave range. If a station is being sought for, it is best to first use a tight coupling which will perhaps allow a number of stations to be heard sending. Having found the station required, it is then possible to change to a loose coupling giving a small range of wavelength so that all other sending stations are eliminated, or in any case, their signals are weakened, and the desired station can be better heard.

It should be particularly noted that in reception the problem is just the reverse to that of transmission, when it is desirable to have as tight a coupling as conditions allow, in order to obtain a greater energy transfer to the aerial circuit.

To obtain further selectivity during reception a third circuit, oscillatory and therefore unlike the detector circuit (which is aperiodic owing to its resistance), may be introduced between the aerial and detector circuit and is known as an "intermediate circuit".

With the Quenched-Spark receivers, since these are assumed

to be for work with Quenched-Spark stations, owing to the sharpness of tuning obtainable with the musical note, this intermediate circuit can be directly coupled to the detector circuit, since without loss of selectivity, this permits of a greater transfer of energy from intermediate to detector circuit.

With the standard "multiple tuner" of the Marconi Company an inductive coupling between intermediate circuit (called "tune") and the detector circuit is used. The direct aerial and detector circuit arrangement, i.e. when for searching purposes rather than tuning an intermediate circuit is not being used, is known as the "stand bi" position.

A comparison of the two receiver circuits of the Quenched-Spark and Marconi system is as follows:—

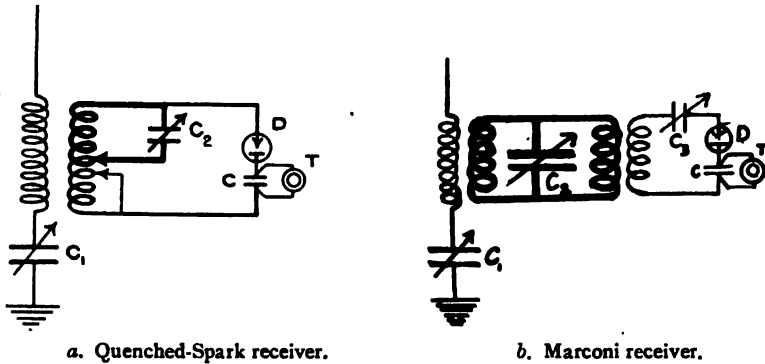


FIG. 43.—Receiver circuits.
Intermediate circuits shown heavy.

With the standard Universal Receiver of the Quenched-Spark system the intermediate circuit is formed very simply. It merely consists of a second air condenser, easily detachable, and the only extra connection to be made is the insertion of two, instead of one, plug connection in the secondary detector coil.

The operation is therefore very simple. With only one plug inserted, a station is sought for by rotation of an air condenser, and variation of the wave range by inserting the plug in different sockets, which varies the receiving inductance step by step, the variation of wave range between each step being easily covered by variation of the condenser mentioned. The desired station having been found, it is then only necessary to insert the second plug, and to accurately tune the intermediate circuit by means of a second air condenser.

The intermediate circuit is only necessary when other stations are "jamming," i.e. causing mutual interference of their signals on the same wavelength. Since selectivity can never be obtained except at the expense of intensity, for ordinary working it is usually found preferable to work without the intermediate circuit.

The "Blocking Condenser".—In the diagrams already given (Fig. 43) it will be noticed that the telephones (T) are in parallel (i.e. shunted) to a condenser.

This condenser is technically known as a "blocking condenser" and usually consists of a small mica and tinfoil fixed condenser, but may be variable.

Its function is to allow the passage of oscillatory currents of high frequency and also to build up from these, by its capacity effect, a potential which causes a continuous or uni-directional discharge through the telephones, which is interpreted by the ear as a click.

For the standard Quenched-Spark receivers this condenser has a capacity of 1000 cms. for use with standard 1000 ω telephones and standard detectors. If, however, other telephones and detectors are being used, it should be a variable condenser so that the most appropriate capacity value can be found by trial, experience showing that it considerably varies the timbre of the note of the signal by resonating with some partials at the expense of others.

Reception of Unquenched-Spark Stations.—With the Quenched Gap, as already explained, the transmitting station only radiates one wavelength and reception merely requires the receiver to be tuned to this single wavelength.

On theoretical grounds it might be supposed that the loss of energy (which results by an Unquenched-Spark station radiating two wavelengths, to only one of which, at any instance, will the normal receiver respond by resonance) might be overcome if the receiver could be tuned to both waves simultaneously.

Were this the case, one of the disadvantages of loss of energy by non-quenching would be overcome, although it would require additional and difficult tuning operations.

Kimauri has used this method of dual tuning, but his results showed that the intensity of signals so received was even less than if only one wave of the same station was utilised, the other being entirely neglected.

Kimauri worked with a particular station, so that the difference of the two wavelengths which it emitted was constant.

For general practical work, the necessary tuning would be very involved, since different stations would not usually be sending upon the same two wavelengths, i.e. if one was to transmit on 600 and 500 metres another might transmit on 600 and 700 metres.

Continuous Wave Reception.—During the past few years continuous wave transmission has received a great impetus, owing to Meissner's discovery that a thermionic valve could be used to generate continuous electrical oscillations, and so to give a more convenient source of continuous waves, than obtained by use of the arc or the high-frequency machine methods.

This has led to an immense amount of work on continuous wave transmission and reception. Also the thermionic valve has been greatly developed for the detection and amplification of spark stations signals.

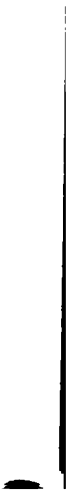
Whilst most of the scientific work of recent years has been devoted to valve work, such forms of receiving apparatus require much more skilled operation, are more expensive, and less capable of nearly automatic reception than crystal detectors. The valve detector, in commercial wireless telegraphy, has far from replaced the older crystal detector, and is described elsewhere in this book.

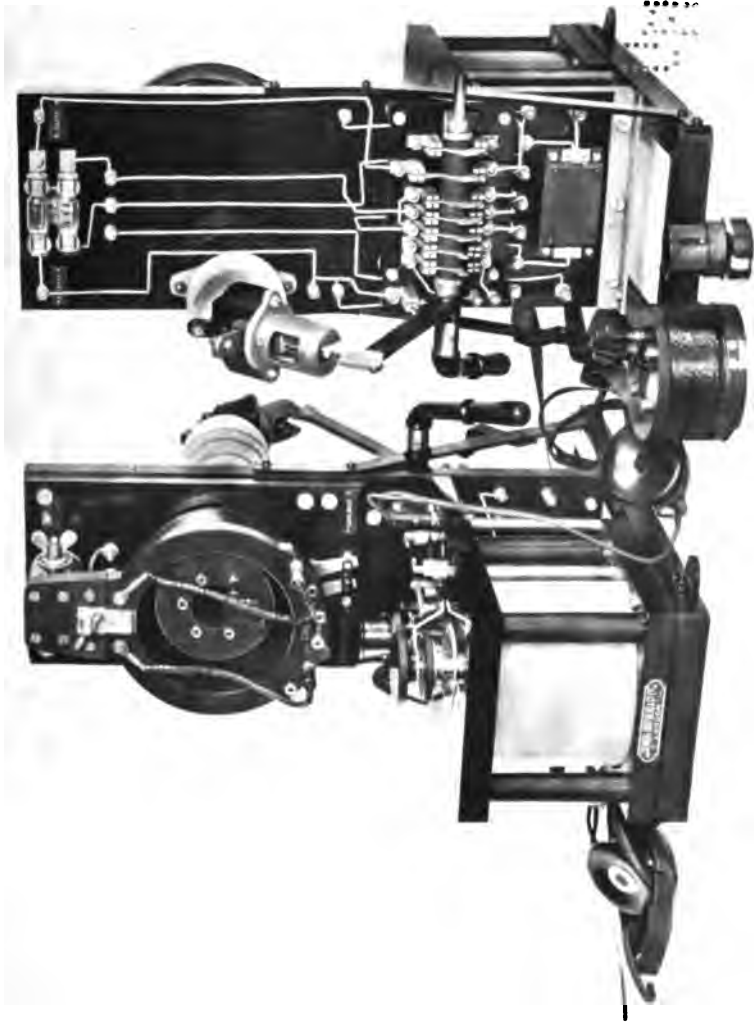
Most of the receivers about to be described, with slight accessory apparatus, work equally well with valve detectors, or by use of a "tikker" can be used for reception of continuous waves by use of a crystal.

During the progress of the Quenched-Spark system many forms of receiver have been evolved. The commercial receivers are nowadays invariably aural receivers, the ranges over which messages can be received being much greater than in the case of the old Morse Inker receivers. The majority of these receivers are remarkable for their simplicity of operation being adjusted by one or two operations and provided with arrangements which automatically interrupt the heavy current transmitting circuits, so that danger is not incurred by operators. The receivers are all very compact and self-contained. In this chapter only the standard types will be described.

The Universal Receiver E 5.—This is one of the most recent and elaborate receivers, and as it is used for many marine and land stations it will be considered first.

An illustration of this type of receiver is seen in Fig. 44. The main features are, the transformer consisting of two coils wound upon insulating drums. The smaller and innermost of these drums is in the aerial circuit and is technically known as





Front view.

Back view.

FIG. 44.—Quenched-Spark receivers. (Universal Receiver, upright type E. 5.)

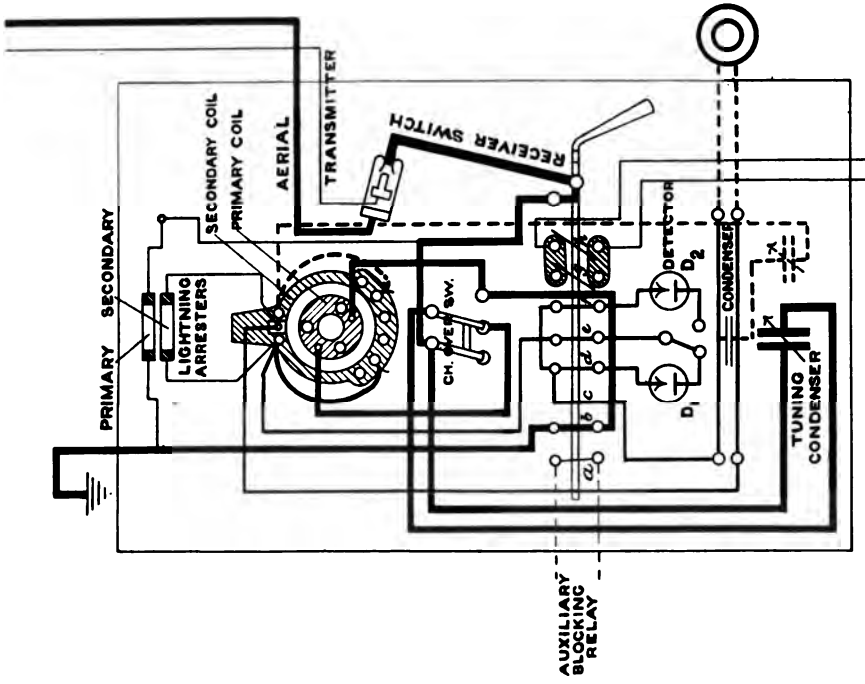


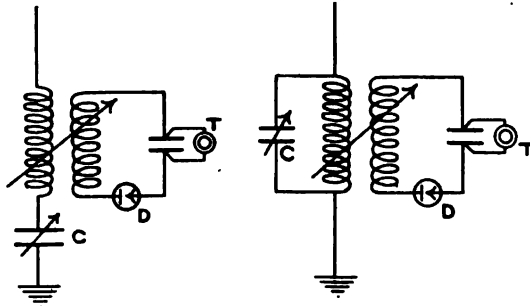
Fig. 44.—Aerial circuit heavy.

[See p. 104.]



the "primary coil". The outer drum is in the detector circuit and is known as a "secondary coil". Upon both of these drums tappings are taken by means of plugs and plug sockets for the various wave ranges which may be obtained by means of the variable condenser forming the base of the apparatus. The secondary circuit is mounted upon a universal joint which permits rotation, first in a plane perpendicular to that of the base and back of the instrument and then in the plane of the face of the receiver. The object of such rotations is for the purpose of varying the coupling between the two coils and hence intensity of received signals. By the dual movement a wide variation of coupling can be obtained. The secondary coil can be clamped in any desired position.

Beneath these coils is a small two pole change-over switch



A. Short waves.

B. Long waves.

FIG. 45.—Quenched-Spark receiver.

marked "long" and "short waves". When the switch is on the position marked "short waves" (Fig. 45, A), the connections are as follows: Aerial, lengthening coil, variable condenser, and earth or counterpoise. When the switch is on the position marked "long waves" (Fig. 45, B) the lengthening coil and variable condenser are in parallel, and form a closed oscillatory circuit, the aerial being connected to one pole of the condenser and the earth or counterpoise to the other pole. With the first position "short waves," all wavelengths from about half the natural wavelength of the aerial up to a wavelength equal to about 1.3 of the wavelength can be received. With the position "long waves" the wave scale begins a little below 1.3 times that of the natural wavelength and goes up to from four to seven times the natural wavelength. The closed circuit method of connection has the advantage that, owing to the condenser acting to the

assistance of the inductive lengthening coil, the latter can be much smaller and more compact than would be the case with the normal method of connection. This is very important when working with aerials of very small capacity.

With both methods of connection, the energy is transferred from the primary transformer coil, which is in series with the aerial into the secondary transformer coil. The latter forms, together with the detector and blocking condenser, an aperiodic circuit. This simplified method of connection has the great practical advantage that, for any required wavelength, only one circuit requires to be tuned, viz. in the case of short waves the aerial circuit, and in the case of long waves, the closed oscillatory circuit.

Two detectors are fitted into the apparatus behind the top of the variable condenser. Either may be put into use at will by movement of a small switch between them.

This arrangement permits of a medium and a specially sensitive detector being used, so that the latter can easily be put into use when the signals are not strong enough to damage it. Also should a detector fail, the other is able to be instantaneously put into use. Beside each detector are plug sockets for the telephones which are shunted across a small fixed blocking condenser at the back of the instrument. Two persons are therefore able to "listen in" at any time and if necessary check each other, or an auxiliary instrument such as an intensifier or call-signal apparatus may be worked from off one pair of sockets, whilst the other is used for telephone reception.

The tuning condenser is a vane condenser usually with air dielectric, but occasionally, if the requirements of the aerial necessitate it, an oil dielectric is used, which increases the capacity and therefore wavelength.

Behind the vertical frame of the receiver is a high-tension terminal and a high-tension switch, to which the leads from the aerials and the transmitter are connected. An arm, which forms an extension of the handle of the main switch on the side of the apparatus, engages with this switch when the handle is turned to the receiving position. By this means, the aerial is connected to the receiver and the transmitting circuit is automatically interrupted. When the handle is turned upwards, the arm is withdrawn from the high tension switch. The transmitter is then automatically connected to, and the receiver is disconnected from, the aerial. Also the various circuits of the receiver are interrupted, so reducing induction effects and risk

of damage. This design has made it possible to keep the parts carrying high-tension current away from any accessible parts of the apparatus, the only high-tension part being the switch, which is insulated and protected from accidental contact.

Upon the back of the receiver are mounted two lightning arresters to ensure that if the receiver is, owing to the carelessness of the operator, left in the receiving position, no damage is done to the coils of the instrument by lightning or other strong external electrical disturbances. These arresters act in exactly the same manner as the Marconi "earth arrester," except that the two carbon electrodes are in a rarified gas. Whilst the gap between them is not bridged by the currents received by the aerial, the slightest induced currents during transmission are sufficient to bridge the gap and so protect the detectors from damage. This gap being in rarified gas instead of air, as with the earth arrester, is correspondingly more sensitive.

This apparatus possesses an exceedingly long wave range. The extent of this range is dependent firstly upon the electrical properties of the receiving aerial. With a normal umbrella aerial of about 1000 cm. capacity, the wave range of the apparatus is approximately from 250 to 3000 metres. With 2000 cm. aerial, the range is 350 to 5200 metres.

The receiver is tuned to an unknown wave in the following manner:—

1. The receiving transformer is coupled fairly closely.
2. The condenser is slowly rotated over the entire scale.

If no signals are received, the plug on the detector coil should be changed to the next contact and the condenser rotated again until all the plug contacts have been tried, and also the plug contacts of the primary coils. As soon as the signals are received the transformer should be coupled more loosely, and then the tuning more exactly adjusted. Any unknown wave can be found and the receiver tuned to it in a very few seconds.

This type of receiver with its great advantages of simplicity and accessibility has been very largely adopted in the later British Army stations, as will be at once evident, by those in a position to refer to the illustration in Army Signals Experimental Establishment, Pamphlet No. 14, entitled "W/T Sets, field, 120-watt, C.W." (see Fig. 162 *e*).

The Universal Receiver (Flat form) E 4.—The receiver just described is designed to stand upright upon the operating table. Such a position is preferable for ship and land installations, but, with many portable military stations where it is necessary to

consider the relative bulk of the apparatus a different form of receiver is used, which lies flat upon the operating table or may be fixed to the wall, and is therefore not so likely to be overturned or damaged by strain, caused by the jolting which occurs when the portable station is travelling over rough country.

This flat form of Universal Receiver is essentially the same as the upright form. Two detectors and telephone plug sockets are provided and a switch to alter the connections for reception of long or short waves. The primary and secondary coils are fitted similarly to those of the vertical type, i.e. upon a universal joint, but are mounted upon the top of the apparatus with the primary coil and not the secondary coil outside. To vary the coupling, the latter rotates upwards. Tappings upon the second-



FIG. 45 a.—Aerial change-over switch.

ary coil are made by means of a small switch instead of by plugs and sockets.

The change-over switch is also fixed in a different position, being at one side, which is more convenient for portable stations (see Fig. 46).

The aerial condenser does not form a rigid part of the receiver, but is a separate item and can be installed in the most convenient place. It is of the usual metal-vane air or oil dielectric type.

The receiver has a range of 310 to 1700 metres with an aerial of 500 cms. natural capacity. This receiver can also be used with an intermediate tuning circuit if required.

With both forms of Universal Receiver when the transmitter radiates more than 5 kw., a second high-tension change-over switch, as shown in Fig. 45 a, is fitted in the most convenient



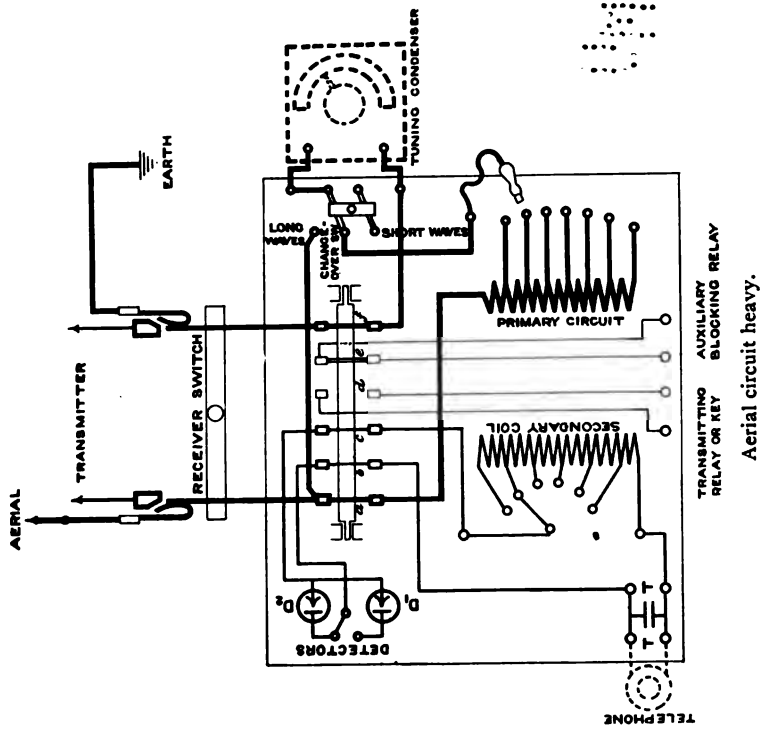


Fig. 46.—Telefunken receiver, universal type. (Flat form E. 4.)

[To face p. 109.

place. This ensures no damage from long sparks which might possibly be able to bridge the normal switch.

The Box Type Receiver.—This form of receiver, Fig. 47, is much more simple in construction than the Universal types and has necessarily a smaller wave range. It is intended for use upon small yachts, aerial vessels, etc., where the requirements are only to receive weather reports and time signals, and the need for transmission of messages is not great enough to warrant the installation of transmitting apparatus.

This receiver is contained in a small cubical box measuring 20 cm. per side. The top is formed of ebonite and upon this is placed a knob for tuning, three coloured wavelength scales, a detector, sockets for two telephones, terminals for connection to the earth and aerial, and a testing buzzer.

Tuning is carried out by rotating, by means of the knob, a circular coil within a larger coil about the common perpendicular axis, so varying their mutual inductance. By means of a change-over switch (positions for which are marked red, yellow, and white), the windings of these coils can be varied to give different wave ranges as indicated by a pointer moving over the appropriate coloured scale. The detector is plugged into the top plate, and when not in use its circuit can for safety be broken by rotation of the detector. A spare detector is also fixed upon the apparatus, but is not in circuit. By means of the two pairs of telephone plug sockets, two persons may "listen in" if necessary. To install the apparatus, it is only necessary to connect the aerial to the terminal marked "aerial" in the top right-hand corner, as seen in Fig. 46, and the earth to the terminal at the opposite corner. To test whether the receiver is in good order, a buzzer and cells are installed within the box, and can be put in use by means of a small rotating switch near the wave scale.

The receiver is designed for use with a single wire aerial, 150 metres in length, and to receive upon three ranges of about 300, 600, and 2000 metres, according to the position of the change-over switch.

The exact positions of the tuning knob pointer for any particular wavelengths must be found after being installed by means of a wavemeter, and marked upon the appropriate scale.

Single Wave Receivers.—These receivers are still more simple in design, and have only an exceedingly small wave range which is chosen for reception of time signals from some particular coast station.

One type is shown in Fig. 48. Connection to earth and aerial

is made by the two terminals on the right-hand side. The receiver is always designed for a particular wavelength, but exact tuning is carried out by means of a small variable condenser, the distance between the plates of which are varied by means of a handle to the left, which opens and shuts the condenser plates similar to the movement of an accordion.

The detector may easily be recognised. A buzzer is installed for testing purposes within the box, and may be set in use by depression of the button in the front of the top plate. Variation of coupling between the aerial and detector circuit is obtained by the handle to the right, which changes the relative orientation of two flat rectangular coils. The telephone is contained in a small drawer in the front of the apparatus, and is connected directly to the apparatus through the back of the drawer.

A later form of time single receiver is shown in appearance and connections in Fig. 49 *a* and *b*.

At the side of the case is a lever *K*, which carries the telephone when not in use. The weight of this when hung upon the lever causes it to move and automatically break the circuits, so that no injury can be caused to the receiver by atmospherics when not in use.

The detector is plugged upon the front of the apparatus and a chart is also fixed here, showing the time signals given out at particular minutes and seconds, etc., by the station for receipt of whose signals the station is designed. To test the apparatus a buzzer is fitted.

DETECTORS.

The detectors used in wireless telegraphy are numerous, but the more common forms may be roughly classified as follows:—

1. **Coherer Detectors.**—These consist of some metallic powder between two electrodes in a sealed tube. The coherer was originally designed by Branly in 1890, and subsequently used by Popoff, Lodge, and later, Marconi, who modified the composition of the powder used. Its action is briefly as follows:—

A metallic powder owing to imperfect contact does not permit low-frequency currents to pass, but under the influence of high-frequency current is rendered a conductor. The powder in a coherer is in circuit with an external e.m.f., but it does not permit current to flow until a high-frequency oscillatory current is received by the aerial. The bridge of powder is then rendered conducting and the external e.m.f. actuates a relay circuit which in turn



FIG. 47.—Box type receiver.



FIG. 48.—Single wave receiver.



FIG. 49 a.—Time signal receiver.

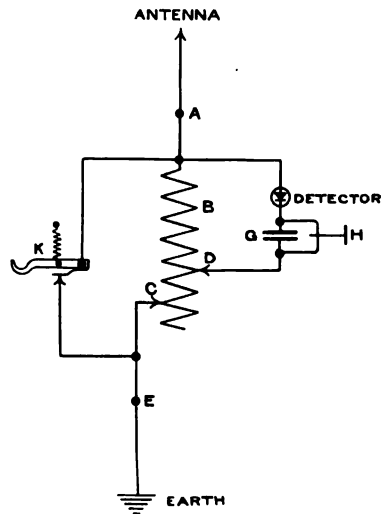


FIG. 49 b.

Telefunken receivers.

[See pp. 109 and 110.
To face p. 110.]

increase of the e.m.f. causes the passage of a current. Such increase may be due to a signal received upon an aerial and the passage of the current of the external e.m.f. is rendered audible by the telephone.

For good working the negative electrode should be a point of about .002 sq. mm. surface. These detectors are extremely sensitive, but require accessory regulating apparatus and attention, and are now largely replaced by contact detectors.

4. **Contact Detectors.**—These are the detectors most used at the present day. They consist essentially of contact points between a suitable metal and crystal such as molybdenite or galena. Such a contact has the property of allowing oscillatory currents to pass in one direction and not the other, so rendering them aperiodic. The passage of these aperiodic currents may be heard by connecting a small condenser in circuit and shunting it with a telephone wound to the correct high resistance.

These detectors are the most sensitive for ordinary working, cannot be greatly damaged, are always ready for use, and require no auxiliary apparatus. They are therefore very widely used.

The Action of Crystal Detectors.—Very many hypotheses have been put forward to explain the action of contact detectors, the chief views being that the phenomena depends on thermo-electric properties, photo-chemical properties, electrolysis in solids, electro-static attraction, etc.

The balance of evidence would seem to be that their action depends on electro-thermal phenomena. Such phenomena depends on:—

1. The variation of resistance with temperature.
2. The Peltier effect, which may be expressed as the causation of an increase or decrease of temperature, when an electrical current passes across a junction of two *different* metals. Conversely a current is generated when such junction undergoes a variation in temperature (made use of in the thermo-couple).
3. The Thomson effect, which produces an electrical e.m.f. between different parts of the same metal at different temperatures.

Any or all of these phenomena appear to cause rectification of the oscillatory currents of wireless telegraphy. The elaborate consideration of these effects is primarily a matter of pure physics, and for further information the reader must be referred to Starling's "Electricity and Magnetism".

The application of such phenomena to wireless reception is

dealt with in the classical paper by Eccles ("Proc. Phys. Soc. Lond.," p. 273, vol. 25, 1913).

Briefly stated the oscillatory current passes across a point contact of minute cross section, and therefore of great resistance. A great deal of the energy is dissipated as heat, which heat raises the temperature in the immediate locality of the point contact, so introducing the Peltier and Thomson effects. This causes the production of a direct current e.m.f.

(given by $e = \pi_2 - \pi_1 - \int \sigma_a dT + \int \sigma_b dT$)
(where π = Peltier coeff., σ = Thomson coeff., and T = absolute temperature)

which produces a current through the telephone, during the continuance of oscillatory wave trains, so giving rise to sound.

The development of such detectors is due to Braun, Lodge, Pickard, Eccles, and many others, and it is interesting to note that such contact of crystals has possibly been used as a reversible engine, i.e. to produce electrical oscillations by passage of a direct current through such a junction (Torikata, Yokoyama, and Kitanuri (T.Y.K. System)).

The substances which may be used for contact detectors are numerous, particularly silicon, boron, graphite, tellurium, arsenic, galena (PbS), iron pyrites (FeS₂), chaliopyrites (FeS + CuS), bornite (3Cu₂S Fe₂S₃), molybdenite (MoS), zincite (ZnO), brookite (TeO₂), iserine ((FeTe)₂O₃), psilomelane (MnO₂), cuprite (Cu₂O), cerussite (PbCO₃), etc.

The most common types are:—

Zincite and chalcopyrite (Perikon), iron-pyrite and gold, carborundum and steel, etc.

Many, such as carborundum and steel, work best when an external e.m.f. is applied by means of dry cells. This obviously causes the contact to be heated until maximum variation of generated e.m.f. is obtained. The maximum temperature is easily found practically, by variation of a resistance or potentiometer in the dry cell circuit maintaining the external e.m.f.

If such a contact has an external e.m.f. applied to it and the resulting current plotted, it gives symmetrical (or unsymmetrical) curves of the type (Fig. 50 a), known as the voltage-current characteristic.

The increased sensitiveness of some crystal contacts by application of an external e.m.f. (potentiometer method) may be inferred from this curve, since by so previously applying an e.m.f. OA, the crystal is in a condition to give a very sudden

increase of current (BC - AD), on the application of an additional e.m.f. during reception, which e.m.f. would otherwise be partly absorbed on the flat part of the curve OD, to produce a relatively small current AD.

Crystals which work best without any external e.m.f. should give a straight line characteristic through the origin.

The actual phenomenon can be inferred from the characteristic curve (Fig. 50 *b*) by selecting a point P on the curve at which the crystal is presumed to be working by application of potential by means of a potentiometer. We now make P the origin for new axes *x* and *y* with respect to time, and on the *y* axis we draw the damped harmonic curve which represents the variation of voltage

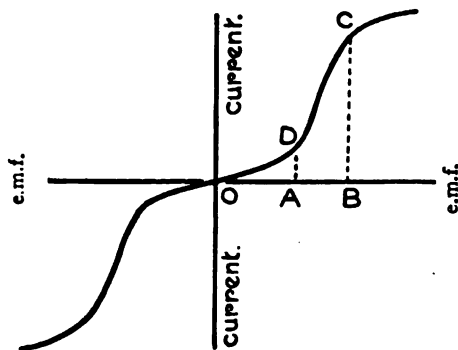


FIG. 50 a.

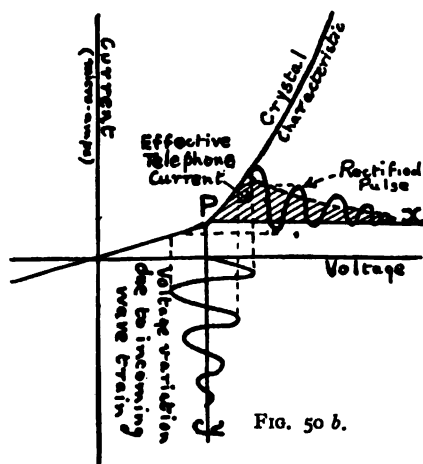


FIG. 50 b.

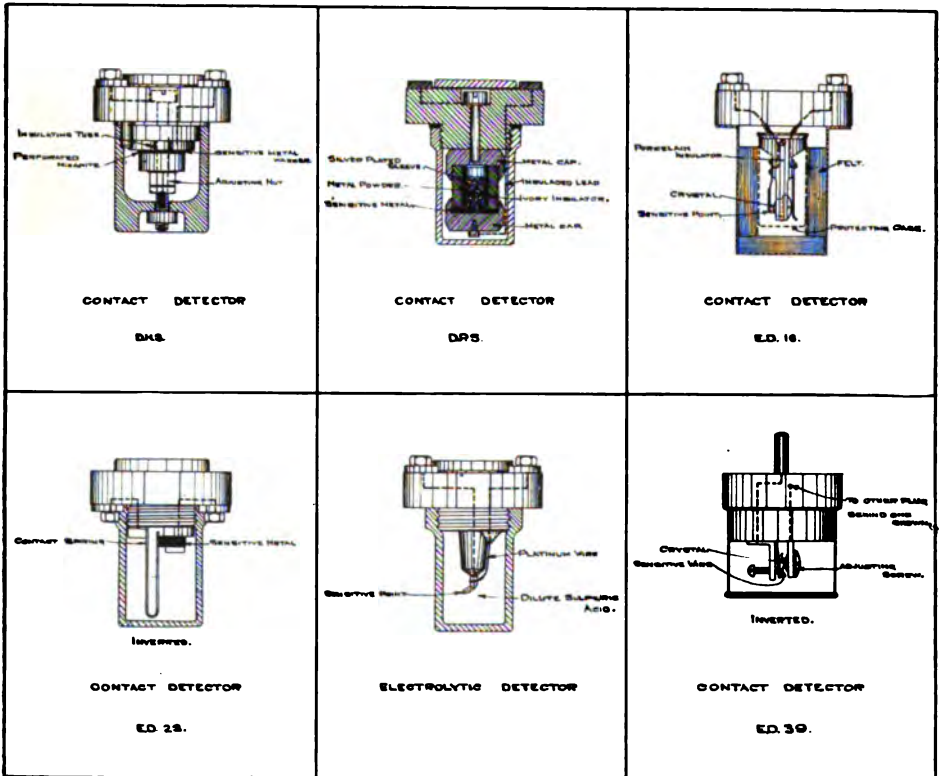
Crystal characteristic curves.

due to the incoming wave train on the aerial; the variation of e.m.f. across the crystal contact will then be the sum of the steady applied potential plus that due to the incoming wave train. This will sometimes assist and sometimes oppose the steady potential. Continuing these values upwards and plotting the corresponding currents with respect to the new *y* axis of time, we obtain the unsymmetrical oscillating curve V, which because of the form of the crystal characteristic is much greater above the *x* axis, and nearly negligible below this axis. The "root mean square" value of this damped unsymmetrical current variations is shown by the shaded area, and owing to the impedance of the telephones the effect is to produce a pulse of unidirectional current for every oscillatory wave train received, causing a move-





A.



B.

FIG. 51.—Detectors.

[To face p. 115.]

ment of the telephone diaphragm and, if the pulses succeed each other at a definite rate, a musical note is heard.

Various characteristics are used to display crystal combinations, but for particulars of power curves, alternating current characteristics, sensitiveness curves, etc., Eccles' book should be consulted.

These curves are interesting on theoretical grounds, but as crystals of the same materials differ enormously as detectors the only practical test is to use them, when many crystals will be found quite insensitive (possibly due to nature of area of contact since on refracture they may immediately become very sensitive). Care should be taken that relative values of resistance of contact and of telephones, coupling, applied e.m.f., etc., are relatively equal during the test.

5. **Special Detectors**, such as the Lodge-Muirhead detector, Fleming valve, thermo-electric detector, for particulars of which general wireless text-books should be consulted. This class also includes the thermionic detector and amplifier of the Lieben type dealt with later.

STANDARD QUENCHED-SPARK DETECTORS.

These are all enclosed in a protective case usually of ebonite, which is provided with suitable contacts to use with the Universal Receivers. When it is necessary to insert the detector with particular regard to the polarity a stop is fitted to the detector which will only engage with a socket upon the detector plate of the receiver. The time necessary to fit or change a detector is negligible. The ebonite cap of about 5 cms. length and 3 cms. diameter was formerly below the surface of the detector plate. With the more recent detectors this is being reversed, and the detector has bayonet sockets, the cap being now above so that when this is removed the detector may be adjusted whilst in the receiver. With specially sensitive detectors, the cap is sealed so that adjustments can only be made by authorised persons.

Before being supplied detectors are adjusted for sensitiveness, but are also adjusted to an internal resistance best suited to the coupling conditions of the receiver: further, they are tested for about 100 times the working intensity and are submitted to a vibration test.

The most important detectors are shown in appearance in Fig. 51 *a*, and diagrammatically in Fig. 51 *b*.

The E.D. 23, E.D. 16, and E.D. 39 are the most commonly used.

D.H. 3 Detector.—In the D.H. 3 type one contact piece leads through an insulating tube to a metal washer, upon the top of which is first a layer of sensitive mineral and then a mica disc which is perforated with a number of holes. A second washer above this disc has a corrugated silver surface, the points of which, by means of a nut, can be pressed through the holes on the mica disc and caused to make a number of sensitive contacts. The sensitiveness may be regulated by adjusting the pressure of the nut upon the bottom washer. The pressure so required is very considerable and to anyone having the idea that detectors require great care of adjustment, the rapidity and ease with which these detectors are assembled and adjusted comes as a surprise. The ebonite cap is held in place by a second nut.

The D.P.S. Detector.—This detector employs a contact surface consisting of a crystalline powder and a washer of another sensitive material. The powder is contained in a bone cylinder with metal endpieces, from each of which connection is made to the contact pieces upon the top of the detector. Insulation in the case of the lead from the lower endpiece is obtained by use of a rubber tube. To obtain a fresh sensitive surface it is only necessary to screw round the lower endpiece.

The E.D. 16 and E.D. 39 Detectors.—These detectors make use of a crystal contact, the crystal being embedded in a metallic cup which is capable of rotation to obtain a fresh sensitive surface. Variation of the sensitiveness is obtained by altering the pressure of the contact point by means of the screws provided. The crystal is embedded in its cup with Wood's metal, to ensure a good contact surface with the detector circuit and to eliminate non-useful thermo-electric effects.

In the E.D. 16 type, the contact is enclosed in a metal case and protected from vibration by felt. In the E.D. 39 type, which is shown inverted, the detector is provided with plug sockets instead of flat contacts and is plugged into an "intermediate piece," which is simply an ebonite disc provided with connected plug sockets so that the detector is totally above the detector plate of the receiver.

The Spring Detector E. 23.—This is a very simple, strong, and sensitive detector. The contact consists of a silver-plated spring which presses against the edge of a layer of crystalline molybdenite held between two pieces of metal.

When the detector requires adjusting, it is only necessary to slightly press the spring further on or off the crystal. If the crystal becomes insensitive, a fresh surface is obtained by inserting

a strip of fine emery paper between the spring and crystal with its rough side to the crystal and lightly pulling it through.

The Electrolytic Detector.—The action of this detector has already been described and the construction is evident. This detector is sealed up so that the acid cannot be spilled or its composition altered.

The accessory regulating apparatus for use with this detector is enclosed in a small wooden box. This contains the regulating resistance and dry cells, also plug sockets for connection to the receiver telephone sockets, and sockets for the insertion of the telephone.

The connections are as follows :—

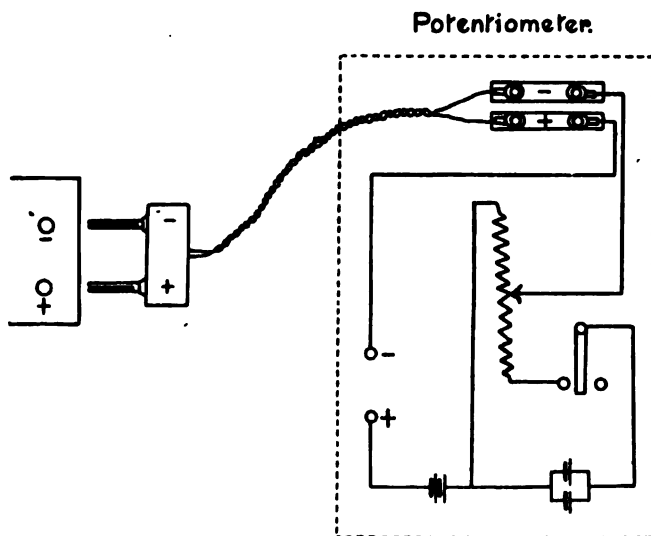


FIG. 52.—Connections of potentiometer. Battery for an electrolytic detector.

As it is necessary to return the detectors after long use for readjustment, a further form of electrolyte detector, known as the Three-Point Electrolyte Detector, is manufactured, which has three times the life of the simple form.

This consists of three small glass tubes sealed at 120° to each other's axes, and rotatable around their common axis. Sufficient acid is sealed up to fill one tube. Should one platinum point electrode become insensitive it is only necessary to rotate the glass tubes around the supports so causing the acid to flow into a fresh sensitive tube. A further advantage of this type of detector is that the acid is completely sealed up and therefore

incapable of being spilled, or being tampered with as regards concentration.

As the polarity of an electrolyte call is important, since it is irreversible, a stop is fitted, which ensures correct polarity when used with the potentiometer.

OTHER RECEIVERS.

All types of receivers for spark signals are essentially the same, and most can be adapted by a ticker, tone wheel, or valve (considered elsewhere) in order to receive continuous wave signals. The author does not, therefore, think that the detailed consideration of the particular design of various companies' receivers will add greatly to the information already given, since no different principles are involved.

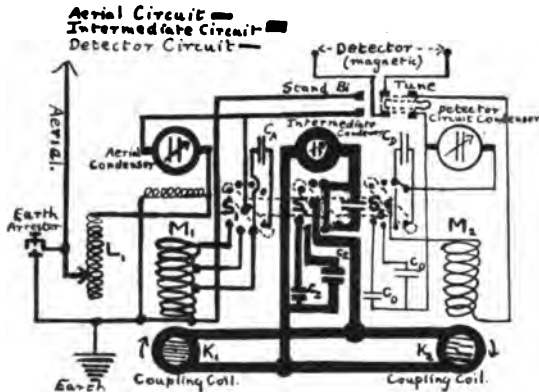


FIG. 53.—Marconi multiple tuner connections.

The most common commercial receiver is the "Marconi Multiple Tuner". This embodies no special features except in construction, which is very rigid but also very inaccessible.

Its connections are shown in Fig 53, and it is usually used with the magnetic detector of the Rutherford type.

In appearance it is an oblong box upon the top of which the three condensers are mounted having in front of them the earth arrester, and a double-throw double-pole switch. In the front of the box is mounted the aerial tuning inductance and a combined triple switch S_1 , S_2 , and S_3 . To the right-hand side is the adjusting handle for varying the couplings K_1 and K_2 of the intermediate circuit to the aerial and detector circuits.

When the double-pole switch is to the left, known as the

"stand by" position, the detector is directly in the aerial circuit, the latter of which comprises the aerial tuning condenser and the parallel inductance M_1 . The wavelength of this circuit (shown mediumly thick in the illustration, Fig. 53), can be shortened by insertion of the small capacity C_A by the switch S_1 which also cuts out inductance. The direct insertion of the magnetic detector in the aerial, though its resistance (compared to the crystal detector) is low, gives a greatly damped aerial. Therefore the selectivity is low, but an unknown station can be more easily and rapidly detected.

Once it is detected the switch is thrown over to the "tune" side and then we have the intermediate circuit (shown very thick) which can be roughly tuned in steps by the small fixed condensers C_I put in circuit by the switch S_2 .

The detector circuit in the "tune" position is shown by thin lines and is adjusted by the fixed capacities C_D .

Coupling of the aerial to detector circuit in the tune position occurs via the inductances K_1 and K_2 .

Exact tuning of all three circuits is obtained by the three condensers, on the top of the instrument, which carries the tuning over the intervals of the contacts of the switches S_1 , S_2 , and S_3 .

This type of receiver is that usually installed, but there are also crystal and valve receivers of very similar construction, for detailed descriptions of which Hawkhead's book should be consulted.

The other common Marconi receivers are: the "Short Wave Multiple Tuner" which is similar to that already described but omits the intermediate circuit, and whilst less sensitive is smaller and easier to adjust.

The "Universal Crystal Receiver," which is very similar in mechanical construction to the multiple tuner, but is more sensitive owing to the use of a low-resistance crystal detector. It embodies no particular new features, except the use of a potentiometer for the crystal.

The valve receiver which utilises two Fleming valves in parallel is much less sensitive than the crystal receiver, but of recent years, the Fleming valves have been replaced by Round valves. This receiver has a small "billi condenser" which is a very convenient type of condenser for fine adjustment and is much used by the Marconi Company. It is a common form of tubular condenser consisting of two metal cylinders, separated by a dielectric, as mica, and capable of giving a fine variation of

capacity by relative movement of the outer cylinder with respect to the inner, along the common axis. They are usually mounted in pairs.

The latest type of valve receiver, Type 30 D. of this company, has deviated entirely from the usual boxed-up type of receiver with its obvious disadvantages of accessibility and is all mounted upon a flat ebonite board. The author has used the same, and it is of very beautiful mechanical construction, but suffers however, by the use of a relatively unstable soft valve as compared to the hard "French" valve of Latour.

Further Receiver Features.—One further ingenious method of tuning due to La Compagnie Générale Radio-telegraphique may be briefly mentioned.

In this two oscillatory circuits are coupled in parallel and the telephone may be switched into either. Signals are roughly found on one closely coupled circuit and then this circuit is slowly mistuned. Since the energy received is divided amongst the two circuits in relation to the wavelengths of the two parallel circuits, when the signals are lost on the first circuit it is evident that all the incoming energy is being received on the second circuit since this is very accurately in tune. The telephone is, therefore, switched over to the second circuit, which is very loosely coupled and hence very selective. This method of tuning forms the subject of Brit. Pat. No. 28,070/1912.

Relative advantages of plug and stud methods of varying inductance and capacity by steps.—For such purposes two methods are used :—

1. By a rotating switch, which makes contact with metallic studs, placed in a circle with the switch as its centre.

This gives a very rapid method of making adjustments and with new apparatus is the best. The studs are then just machined and are all level and the switch makes good contact. Unfortunately, with use the pivoted switch works loose and the studs become uneven, so that the contact from stud to stud is very different, and on a well-used instrument particular studs may not make contact. In any case the variation of pressure of the contact between different studs varies the resistance of the different circuits, so that the electrical properties differ and introduce errors.

When the switch and stud contacts work loose evenly this can be overcome by taking up the slack of the central rod of the switch. Unfortunately, in the class of instrument which uses this method of variation, the requisite nut is not easily accessible,

and even when the instrument is taken down, which requires some time, it is very easy to slightly damage the various leads to the under sides of the studs and not to notice this until the instrument has been reassembled.

This objection becomes a very serious consideration when a day and night watch is being kept (as during interception work during the late war), necessitating continuous tuning and movement of the switch. Several examples of these receivers came under the author's attention, and in one case an entirely new instrument did not last two weeks.

2. By plug sockets.

This takes a little greater but hardly appreciable time for adjustment.

It is preferred by the author since the plug connection can be split, and when pushed firmly home, always ensures a good and even contact, which remains the same after years of use.

This method is much favoured on the Quenched-Spark system. Whilst the army apparatus first favoured the switch method, the later apparatus, as the continuous wave valve apparatus, where good and constant contact is very necessary (to prevent objectionable parasitic noises), appears to favour the plug method.

Note on Balanced Detectors.—Most wireless books deal with balanced crystals and balanced valves, due to various investigators, which are said to eliminate atmospherics.

In theory they do so most admirably, but in practice this is far from the case. The author well remembers having such a balanced crystal device in his care, which gave no results except to weaken signals generally, and even the manufacturers' experienced engineer, after devoting much attention in order to improve matters, preferred to entirely abandon such a device in favour of a single detector and elimination of atmospherics by physiological accommodation of the ear.

The author, whose general experience with balanced detectors has been consistently unsatisfactory, does not think any useful purpose can be served by devoting further space to these devices, which appear to work better in patent specifications than in practice. They will be found, however, in many books on wireless telegraphy.

CHAPTER V.

ACCESSORY TRANSMITTING APPARATUS.

STRICTLY when dealing with accessory transmitting apparatus the emergency transmitter installed upon ships should be included; but as this consists essentially of a heavy current rapid-break induction coil worked from accumulators, in conjunction with the normal excitation circuit of the wireless station, it does not call for further mention.

THE SPARK GAP IGNITION DEVICE.

This device, due to Meissner, is the subject of the British Patent No. 16,827, of 1912, and is a means of producing the following effects in wireless transmitters:—

1. Independence of the discharge to variations of the direct current supply actuating the transmitter.
2. Limitation of the energy of discharge and the production of a continually variable range of transmitted energy.
3. Good quenching of the discharge, and hence greater purity of the emitted note and greater range.

The ignition device is in reality a separate, small, highly damped excitation circuit in parallel to the main transmitter and working off a separate transformer at a much higher voltage. In the ordinary Quenched-Spark and all other spark transmitters the resistance of the spark gap does not break down, until the accumulation of charge in the condenser supplies the necessary voltage to bridge the gap. The rate of this accumulation of charge will depend upon the current and voltage of the direct current supply actuating the station. Since variation in this supply will cause similar variation of the speed of the motor and the excitation of the alternator, the rate of breaking down of the spark gap, and hence tone of the emitted note, will vary with the supply, which it is impracticable to keep constant within fine limits. With ordinary working, therefore, the note is generally slightly impure.

The amount of energy involved in the discharge is that which it is possible to store electro-statically upon the condenser

until the spark discharge takes place, so that in an ordinary excitation circuit with no ignition device, the energy radiated can only be varied by increasing the number of spark gaps, so requiring a higher breakdown voltage and a corresponding accumulation of energy.

This method of variation is not continuous, since two spark gaps cause the radiation of four times as much energy as one gap, three gaps nine times as much ; i.e. the radiated energy is proportional to the square of the number of spark gaps. It is, therefore, impossible to vary the transmitter to radiate twice, three, or five to eight times the amount of energy. With the ignition device the discharge of the condenser is independent to the number of spark gaps, and hence independent of the capacity

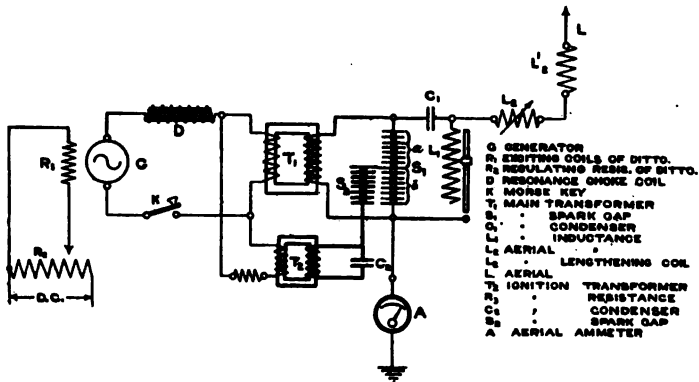


FIG. 54.—Connections of the ignition device.

of the main condenser. This is brought about according to the arrangement shown in Fig. 54. A small transformer T_2 feeds a second small highly damped excitation circuit having a relatively small condenser C_2 , which discharges across a small spark gap, shown diagrammatically by S_2 . This gap is in reality a part of the main spark gap S_1 , which has a corresponding main condenser C_1 and transformer T_1 .

The rate of oscillation of the auxiliary excitation circuit is made much higher than that of the main excitation circuit, and the latter has not a sufficiently high voltage to break down its spark gap S_1 , but is only sufficient to bridge a number a of the gaps. The ignition device has a voltage great enough to bridge the remaining spark gaps b , and the discharge of the main transmitter over the total gap a and b is brought about by the small

transmitter sparking over the part b , so ionising these gaps and permitting the main transmitter to discharge through them.

The discharge of the main transmitter is therefore quite independent of the capacity of the main condenser, the charging of which it is difficult to render independent to variations of the supply current, but is entirely dependent on the secondary voltage of the small transmitter, which may be accurately adjusted by a regulating resistance. This resistance is continually variable, and the energy of discharge is therefore likewise continually variable. Further, since the secondary voltage of the small transformer T_2 is much higher than that of the main transformer T_1 , and the capacity of the corresponding condenser C_2 is smaller than that of the condenser C_1 , variations of the direct current supply have very little effect upon the discharge of the small excitation circuit. The main excitation circuit is therefore independent of such variations, and does not require continual adjustment, since once the ignition circuit is adjusted the discharge does not vary.

The ignition circuit only requires a small and negligible proportion of the total energy, but by variation of the regulating resistance R , the voltage of this circuit can be adjusted, so giving an increase of the rate of sparking and correspondingly an increase of the energy radiated by the main transmitter, which is so capable of continuous variation, irrespective of the number of spark gaps it can itself break down. This variation can be continuously varied from 1 to one-twentieth of the highest power the main transmitter can radiate.

The third advantage of this device, namely, good quenching, is due to the fact that the ignition circuit being highly damped, its oscillations are immediately quenched. Since the main excitation circuit is never able to bridge the total number of gaps $a + b$, the oscillations of this circuit are also immediately stopped at the same time as those of the ignition circuit, and the connected energy is therefore all radiated by the aerial circuit at its natural period, so producing a good and sustained note. This renders it unnecessary to tune the main excitation circuit, but only the aerial circuit, and any inaccuracy in the tuning of the ignition circuit is negligible since the energy of this circuit, and hence mutual reaction with the aerial circuit, is small in comparison to that of the main excitation and the aerial circuits.

An advantage of this device, that would appear to have escaped the Telefunken Company's notice, at least in their patent specification, is the fact that this ignition apparatus will permit

of much better high-speed automatic transmission. In such transmission the practical difficulty is to obtain a rapidly acting relay, which will carry the necessary current, since the construction must be light to avoid delay, due to mechanical inertia.

The present device, however, permits of such a transmitting relay being inserted in the low-tension side of the auxiliary circuit, whilst the main low-tension circuit is completed. Hence the relay will only have to carry a small current, whilst, if the voltage of the main circuit is insufficient to completely bridge the spark gap, the discharge of the latter is completely determined by the relay in the auxiliary circuit. This relay, carrying only a very little energy, can be made extremely light so ensuring very rapid working.

OTHER IGNITION DEVICES.

Sawtelle's Method.—Ultra-violet light falling on a metallic surface gives rise to ionisation. Sawtelle has caused spark discharge to take place by throwing ultra-violet light from an iron-magnesium arc on to the negative pole of the spark gap, and by means of a rotating mirror, the periodic incidence of such light upon the gap can be varied.

Sawtelle did not use this method of ignition for wireless purposes, but Eccles has suggested such a use.

Whilst this method could undoubtedly be used, it would suffer from the drawback, as compared to the device already dealt with (only requiring an additional non-rotating transformer and condenser), that it would require much additional apparatus, which would be rotatory instead of static, and therefore require continual control. Also the operator would have to be shielded from the harmful physiological effects of the ultra-violet light.

Galletti and Marconi's Methods.—As ignition devices, Eccles describes a method originally due in principle to Galletti, and subsequently modified by Marconi.

In the present writer's opinion neither of these inventors intended their apparatus for ignition purposes, so much as for the production of continuous undamped waves, by the fairly obvious method of causing over-lapping of damped wave trains. In neither case is there any direct limitation of the amount of energy involved in the spark discharge, a characteristic of the method already described.

Galletti's method (British Specification No. 15497, of 1910), is in effect the parallel arrangement of a number of oscillatory circuits, of which the physical characteristics of resistance and

capacity are so determined, that they break down in a regular sequence across a common spark gap, so giving a regular sequence of damped wave trains, the summated effect being a more or less continuous radiation from the aerial circuit.

Marconi's arrangement is essentially similar to that of Galletti, i.e. a number of oscillatory circuits arranged in parallel, but the periodicity of each circuit's discharge is determined by the use of rotating spark gaps in each circuit. Eccles shows this disc discharger applied, to regulate by its speed, the discharge of the Cooper-Hewitt mercury vapour gaps, and to the ordinary Quenched-Spark Gap. As this method is for the production of continuous waves, it is best described elsewhere (Chapter XIII.).

By far the most interesting feature of Marconi's method is the inclusion of Quenched Gaps with the rotating disc discharger. Since this disc discharger is claimed to provide a quenched discharge, if true quenching were produced by the rotary discharger (in addition to its being a method to provide a musical note (see Chapter II.)), the addition of Quenched Gaps in circuit would appear to be unnecessary.

THE ROTATING HELIUM TUBE.

The ignition device just described is to maintain regular sparking of the transmitter, but does not give a direct method of measuring the frequency of the sparks. This measurement is obtained by utilising the well-known property possessed by helium of glowing when a potential difference is applied to the ends of a tube containing this gas. If the current is continuous a continuous glow is obtained, but if an alternating current is used two distinct sparks are obtained for each cycle corresponding to the peaks of the harmonic voltage curve. To measure the number of sparks it is only necessary to connect an inductance, in series with a helium tube, by mutual inductance with the excitation circuit in which a current is so caused to flow. If, however, the spark frequency amounts to the frequency of 1000 per second, it is not, of course, possible to count these by the human eye, and a device must be used to enable them to be counted. This device consists of mounting the helium tube upon a blackened disc, as shown in Fig. 55 *a*. If this disc is caused to rotate by means of a motor, first a continuous ring of light will be seen which, as the speed of revolution increases, will split up into a number of bands radiating from the centre. This effect is due to the persistence of vision of the human eye, i.e. before the image upon the retina of one discharge disappears, the helium tube has rotated into the same position and

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SECRET



FIG. 55 a.—Helium tube apparatus.

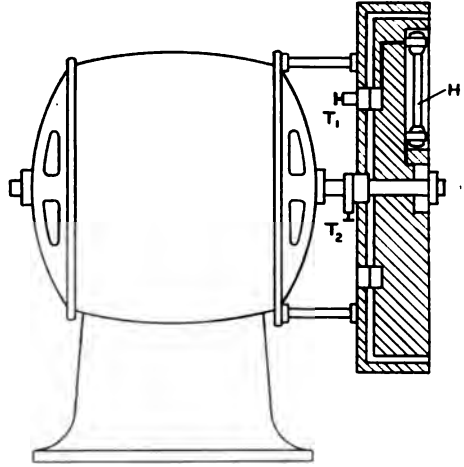


FIG. 55 b.—Connections of helium tube apparatus.
[See p. 127.]

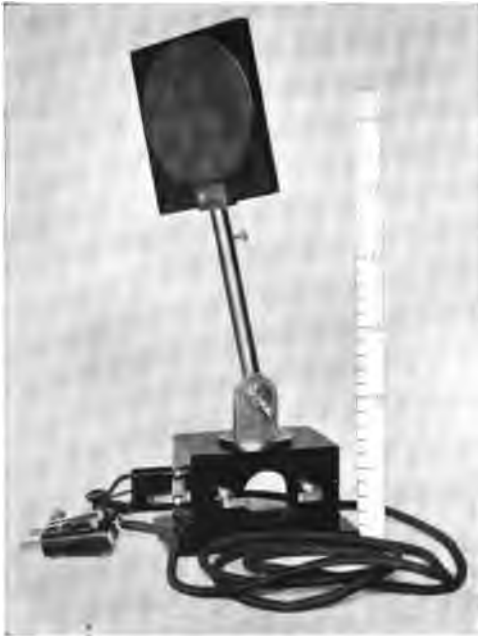


FIG. 56 a.—Aperiodic circuit.

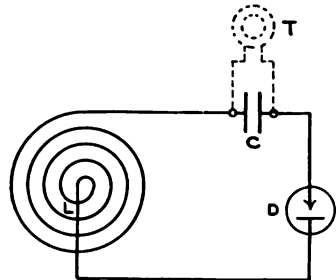


FIG. 56 b.—Aperiodic circuit connections.
[See pp. 127 and 128.]

given another image, so that the effect is that of a stationary band of light.

The quicker the rotation of the motor driving the disc the more are the images separated, and one, two, four, eight, etc., bands may be seen. Knowing the speed of revolution, the number of discharges per second can be counted. For example, with the tube rotating at 3000 revs. per minute, i.e. 50 revs. per second, for 1000 sparks per second of a transmitter 1000 discharges of the tube take place, and 20 luminous images are seen. In general if—

n = the speed of the motor rotating the tube (revolutions per minute),

s = number of lines which are seen,

z = number of sparks,

then $z = (s n)/60$ per second,

and to easily count the images it is necessary to increase n so that s , the number of lines seen, is from one to eight.

Connection from the inducing coil (Fig. 55 *b*) is made to the tube by means of the shaft of the motor at one end (T_2), and an insulated slip-ring working against a brush at the back of the disc at the other end (T_1).

If the speed of the motor-generator actuating the transmitter varies and not the speed of the helium tube motor, the sparks become blurred, and it is therefore necessary that these be synchronous. This is obtained in practice by use of a 50-period motor, which obtains current from slip-rings upon the armature of the motor-generator supplying energy to the transmitter.

The apparatus is extremely accurate, and requires very little space or attention. It is usually mounted above the motor-generator switchboard, and can be put in or out of action as desired by means of a switch.

THE APERIODIC CIRCUIT.

Upon small ship installations where the helium tube apparatus already described is not supplied owing to questions of expense, etc., it is necessary to have a small, reliable, and comparatively simple apparatus to control the note of the transmitter.

The apparatus used is known as an "aperiodic circuit". It consists of a circuit having an inductance, contact detector, and capacity, in parallel to which are sockets for a head telephone (Fig. 56 *b*). Oscillatory currents induced in this circuit will be rendered aperiodic by means of the detector, and audible by means of a telephone placed in the sockets. The note given out by a transmitter is so rendered audible, and adjustments can be

made to the apparatus to produce the best note as heard in the telephone, when the transmitter is known to be correctly adjusted.

This testing apparatus is made in several forms, one of which is shown in Fig. 56 *a*, and is designed to be fixed in an accessible position upon the wall of the wireless cabin or room. The inductance coil is in the flat case which can be rotated about its stand in order to produce the best mutual inductance between it and the transmitter. The detector is plugged into the base which contains a fixed condenser, and for use it is only necessary to plug the head telephone into the sockets seen to the left of the stand. Other forms of aperiodic circuit are made in which the detector and telephone are directly plugged into the inductance case upon which the condenser is also mounted. With this form the aperiodic circuit is held by hand in the best relative position to the transmitter. It suffers from the disadvantage of being mislaid, which cannot occur with the fixed type illustrated.

This apparatus is exceedingly simple and neat. Any similar apparatus does not appear to have been introduced by the Marconi Company to control the note given by their musical rotary disc-discharger. At least, with a large Quenched-Spark Automobile Station supplied by Siemens for use at G.H.Q. (France), the officer in charge, previously a Marconi employée, was, for some months, completely puzzled as to the use of the aperiodic circuit, supplied with the installation, until he requested the author to inform him as to its use.

AUTOMATIC TRANSMITTING APPARATUS.—THE HIGH-SPEED WHEATSTONE TRANSMITTER.

For communication from ship to ship, or from ship to land, the speed of telegraphing need not usually exceed the normal speed of hand working, namely, 20-30 words per minute.

For traffic between land stations, however, the speed of transmission can be advantageously increased up to 100 words per minute, or even more, if heavy traffic is engaged in. Automatic transmitters and receivers have therefore a fairly large field of application.

For the former, some type of Wheatstone transmitter is used to operate intermediate relays to interrupt transmission, and corresponding reception is carried out by means of a photographic or phonographic receiving apparatus. Various forms of Wheatstone transmitters are used, working upon the usual weight-driven or motor-driven principle, but it will be sufficient to describe one form.



FIG. 57 a.—Automatic sender.

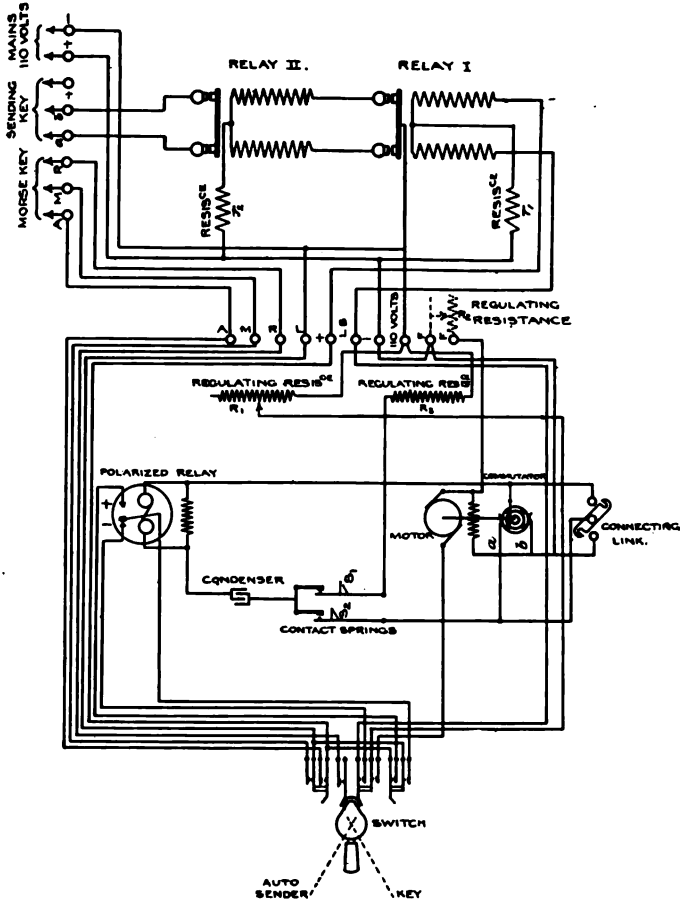


FIG. 57 b.—Connections of automatic sender.

[To face p. 129.]

This apparatus (Fig. 57 *a* and *b*) is in reality a special form of double current transmitter in which the moving parts are rotary instead of reciprocating, as is usual. The driving power is derived from a motor *M*, and in effect the rotary transmitter is very much the same as the ordinary Wheatstone apparatus, sending marking and spacing currents to the wireless relay under the control of a perforated strip.

The method adopted, however, is somewhat different, as instead of two reciprocating needles which enter the holes of the perforated slip, two contact springs S_1 and S_2 (Fig. 57 *b*) are arranged side by side, which alternately drop into the holes in the strip, one spring being slightly in advance of the other. In place of the ordinary reverser or compound contact there is a polarised relay which is operated by the charging or discharging current of a condenser under the control of the springs S_1 and S_2 in the holders *a* and *b* by means of a commutator upon the motor spindle. Immediately the marking spring S_1 drops into a hole of the perforated slip the D.C. current (as directed by the commutator) brings the tongue of the relay to the spacing spring S_2 , and charges the condenser. Hereupon the commutator connects the relay to the spacing spring. Immediately a spacing hole causes the spring to drop and make contact, the condenser discharges and throws the tongue of the relay over to the spacing contact. For each revolution of the motor the strip travels forward the distance between the two guiding holes in the strip, and the charging and discharging commutator connections are made at each half-revolution for a period of a quarter-revolution. The speed (and hence sending speed) of the motor can be varied electrically by the rheostats R_1 and R_2 , and mechanically by the brake *B* attached to the motor spindle. For high speeds a second rheostat R_2 is inserted between the terminals *F*.

The working of the relay is absolutely reliable with heavy currents, and is not affected even by bad adjustment. Terminals *A*, *M*, and *R* are provided for ordinary key transmission if desired, the apparatus being changed from automatic to hand by means of a switch—and in the latter case the motor is short-circuited by the connecting-link.

The current from the polarised relay passes to the terminals *LB*, and hence to the intermediate relay (1) working direct from the D.C. supply at reduced pressure by means of resistances r_1 and r_2 . A second relay (2) is then actuated, and from this the normal wireless relay of the wireless transmitter.

All these relays carry heavy current, and must be designed to be both electrically and mechanically substantial, but to have very little inertia to permit them to rapidly follow the Wheatstone apparatus, the whole success of high-speed transmission depending upon this.

The use of high-speed automatic transmitting and reception apparatus for wireless purposes is a straightforward engineering proposition, and whilst the apparatus just mentioned is that installed in Quenched-Spark installations, practically every wireless company has its own particular high-speed transmitter, but the differences are those of detail only and not of principle.

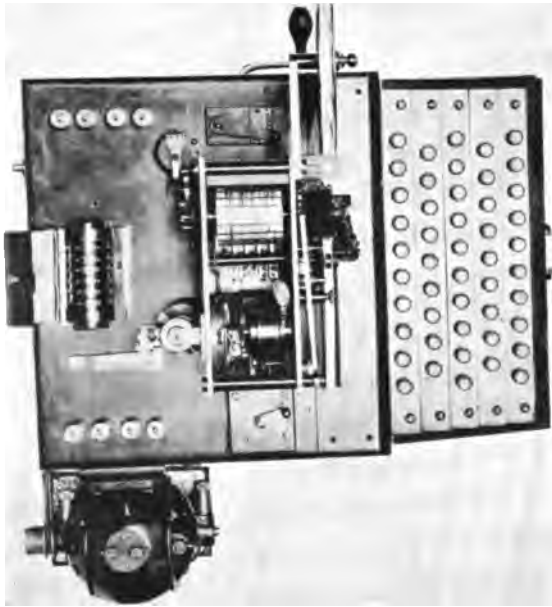
The Hovland Typewriting Apparatus.—This apparatus is the invention of Captain Hovland, of the Norwegian Navy, and aims at the transmission of messages by operation of a keyboard similar to that of a typewriter, so that messages may be sent by persons without a knowledge of Morse Code and messages received in printed characters.

A further aim of the apparatus is absolute secrecy of telegrams. This is attained by means of a device known as a "Cryptograph," which is built into the printer. By means of this device the signal combinations can be rapidly changed, i.e. dots and dashes other than the ordinary Morse characters are used. If two or more stations are to communicate with one another, their cryptographs must be set to a common combination. This can be done either by arrangement on each occasion when two stations wish to communicate, or upon the basis of a general predetermined scheme.

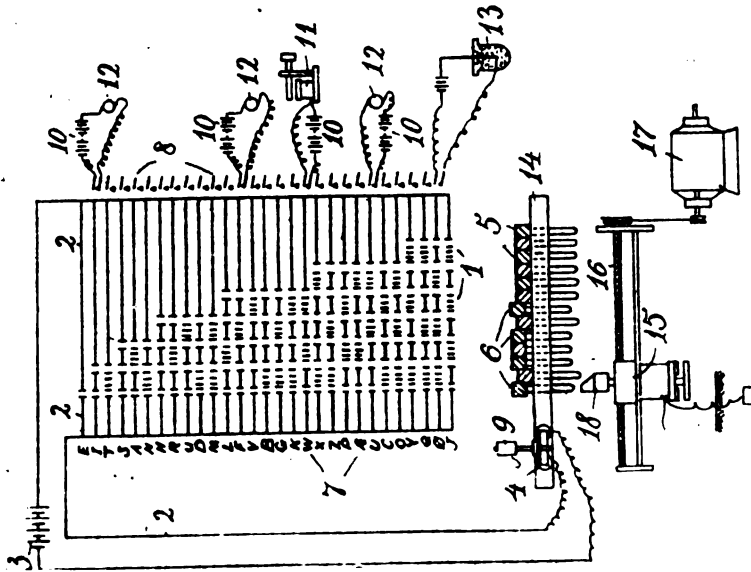
For transmission the apparatus is worked like an ordinary typewriting machine. If it is wished, for example, to transmit the word "London," it is merely necessary to press the keys marked with the letters London, irrespective of the adjustment of the cryptograph. A rotating clockwork or electrically driven contact then makes contact in the transmitting relay circuit for given times as determined by the dots and dashes of the depressed letter. All stations, the cryptographs of which are adjusted to the same numbers, will so receive the word "London" on the paper strip. Other stations, which do not know the combination to which the cryptograph is adjusted, receive only a meaningless mixture of letters or figures. In order to discover the real meaning of the telegram, it would be necessary to try 5040 different combinations of the alphabet.

The reproduction of telegrams in printed characters instead of in Morse Code is attained by Captain Hovland by the follow-





a.



b.

FIG. 58.—Hovland typewriter.

[To face p. 131.]

ing means. The signals received are reproduced in metal Morse type by means of metal contact pieces. When this Morse type is produced it is carried over several rows of metal contacts. These rows of contacts, Fig. 58 *a*, are so formed that they have one or more interruptions corresponding to the different Morse signals. These interruptions form the negative, and the metal Morse type forms the positive pole of a local circuit. When the positive type, i.e. the Morse type, comes opposite the corresponding negative type the interruption in the latter is bridged over conductively and the circuit through the printing magnet coil is closed, the paper strip being pressed against the letter or character corresponding to the row which is bridged over.

In Fig. 58 *b*, showing the apparatus from above, on the right are seen the rows of contacts which are arranged round a drum. In front is the keyboard and at the back the cryptograph. This device provides for absolute secrecy of messages, and also saves time and work, since the translation from ordinary writing to code and vice versa is effected automatically.

Captain Hovland has worked out five different designs of this apparatus, and practical tests have been carried out, the apparatus being operated by means of both coherer and electrolytic detectors.

The speed which can be attained with this apparatus, fully meets the utmost requirement of actual practice, speeds of 60 to 100 letters per minute being possible.

The range over which the printer will work depends solely upon the range of the wireless apparatus.

The apparatus is purely a mechanical device to permit secrecy for military purposes and to save time necessary to change a written message into code. It offers no particular interest from the point of view of wireless technology, and as the apparatus has not come into extended use, those readers wishing for further particulars of the mechanical construction are referred to the "Jahrbuch der drahtlose Telegraphie und Telephonie," 1912.

Secrecy in Wireless Work.—Various other methods have been devised to obtain secrecy in military wireless work, chiefly by synchronous alteration of wavelength at sending and receiving stations. This is the method adopted by the Marconi Company, described in the 1913 "Year-book" as follows:—

"Perhaps the surest method of obtaining secrecy has been adopted in the design of some of the Marconi field stations.

"This method is to change the wavelength of the transmitter at frequent intervals from one fixed wavelength to another. In

the ordinary way the time taken to change the wavelength of a transmitter is a matter of some minutes (a few seconds with Quenched-Spark transmitters.—Author), and to change the wavelength of the receiver a matter of some seconds. But in the stations above referred to the different components of the synchronised circuits of both transmitter and receiver are brought to a three-position switch called the 'change tune' switch, one such switch being fitted to the transmitter and one to the receiver. Each position of the switch changes the wavelengths to a definite value, and the switch being operated by a single handle, the time taken to change the wavelength of either the transmitter or the receiver is thus reduced to a fraction of a second. The operator can therefore change his wavelength or 'tune' after every three or four words to any of the three waves, to which his switch has been adjusted, without waste of time and by sending a code letter, indicating to which 'tune' he was about to change before each change. The operator at the station with which he is communicating, and whose receiver is similarly fitted with a switch, would be able to follow him without difficulty, whereas other stations would only be able to read at the most a few disjointed words here and there, which would be of little or no value in the hands of an enemy.

"Of course, if such a station were always to work on the same three waves, the enemy's station would soon measure the waves, and devise a method of standing by on all three waves, but the apparatus is so arranged that the value of each wave corresponding to the different positions of the change-tune switch can be varied to anything between wide limits, so that each day, or even several times a day, the values of the three wavelengths can be themselves changed."

The idea is commendable, but the author had charge of two Marconi lorry stations in France, and has never known the change-tune switches which were fitted to be used in actual practice. If we analyse any method depending on rapid change of wavelength, we must remember that the capacity of a normal aerial for efficient radiation limits the wavelength of even a large military station to a range of 300 metres to 900 metres, or at the most 1200 metres.

If we also remember that a tightly coupled receiver on 600 metres will also pick up strong working signals, desired in military work, from 450 to 750 metres, we can easily see that however much any method of change of wavelength is used, it will only require three or four tightly coupled receivers to completely

pick up any messages which may be transmitted from as many opposing stations.

Even this number may be reduced to two or even one by a skilful operator, or by use of a "double-receiving switch" described in the next chapter.

Hovland's apparatus, dependent upon automatic variation of the letter code, certainly offers advantages over any method depending upon change of wavelength.

Both methods are rendered unnecessary if a suitable code is adopted, and in practice it is far too dangerous to transmit any message without the use of a code.

For example, if the transmission of the word "Quenched" signifies "The attack on the sector is to commence at 6 a.m.," unless the enemy already knows the significance of the word "Quenched," it is immaterial whether he intercepts it or not.

If he has gained a previous knowledge of the code, it is unlikely that he will have a less knowledge of the actual intended tactical operations, in which case, secrecy in wireless telegraphy by any method is superfluous.

The author in a series of trench installations in France, in the actual front trench area, had a system whereby the code could be changed ten times in as many minutes. Such codes were given sealed to the N.C.O. in charge of each station and were only known to the author, until required for use, and the whole series was regularly changed.

In spite of many affirmations to the contrary regarding "syntonic" wireless telegraphy, secrecy in wireless telegraphy may be dismissed as non-existent, and most statements made to the contrary have a commercial basis.

Certainly Hovland's apparatus which utilises a code other than Morse, and therefore not readily read, if it is at all possible to do so, is the best yet evolved, but whether this would stand the strain of trench warfare is very questionable, and speaking from very considerable experience, the author would not like to trust it with ordinary plain language.

The problem of military wireless telegraphy, which alone has any need of absolute secrecy, is not that of secrecy, but to prevent location of the wireless station by the enemy, by means of wireless direction-finders, or aircraft, so involving the subsequent direction of attention to the station by enemy artillery or aircraft.

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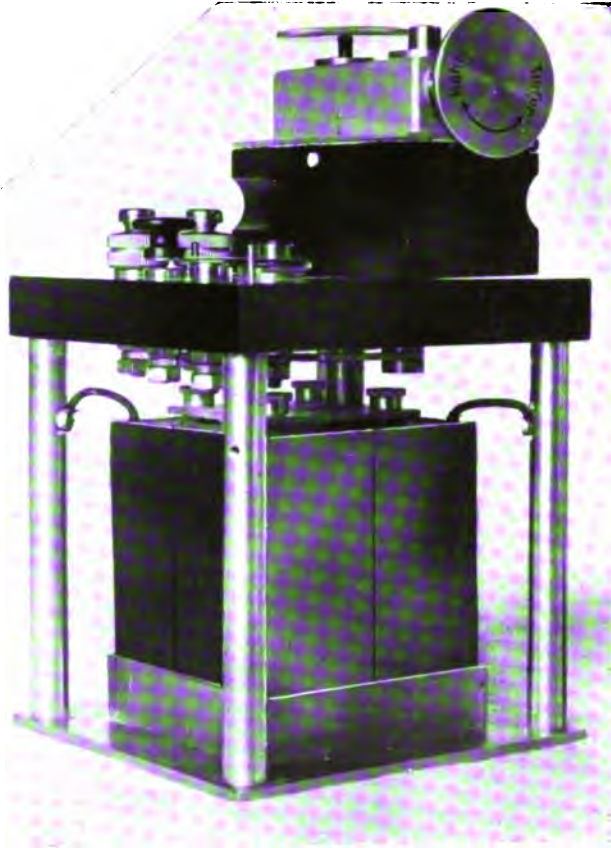


FIG. 59 a.—Buzzer.

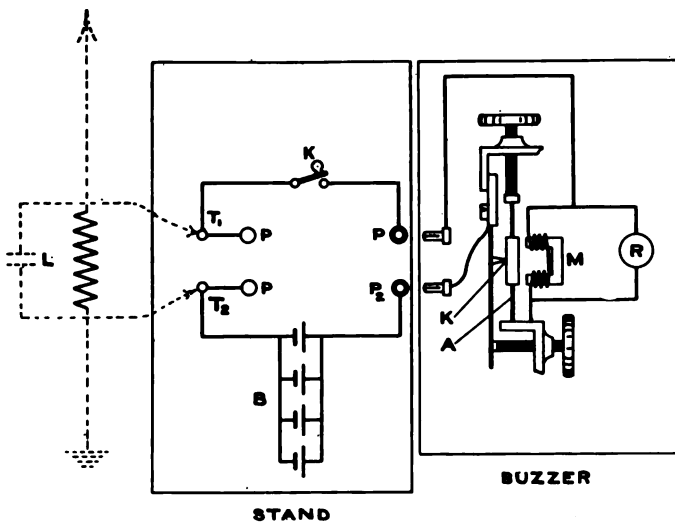


FIG. 59 b.—Connections of buzzer.

[To face p. 135.]

CHAPTER VI.

ACCESSORY RECEIVING APPARATUS.

THE BUZZER.

JUST as it is necessary to have some means, such as the aperiodic circuit, to control the transmitting side, so it is necessary to have a similar means to control the receiving side of a wireless station. This controlling apparatus is provided by the buzzer and more elaborately by the wavemeter, which controls both transmission and reception, but is usually a more complicated and larger instrument, and not often supplied with commercial stations.

The buzzer is an instrument which produces rapid interruptions of a direct current, giving a rapid series of uni-directional impulses, which, if they have a frequency of from 600 to 1400 per second, approximate to the oscillatory current received from a wireless transmitter of the Quenched-Spark type.

One form of buzzer is shown in Fig. 59 *a*, the buzzer proper being enclosed in the metal case on top. The connections of the apparatus are as shown in Fig. 59 *b*.

The battery of dry cells B supplies current which may be interrupted by a Morse key K and is connected to the aerial or circuit to be tested from the terminals T_1 and T_2 .

When the Morse key is depressed current flows from the positive pole of the battery, the inductance of the aerial under test, through the Morse key K to the plug P of the buzzer proper. This consists of an electro-magnet M, and a vibrating armature A, from which the current returns through the contact K to the plug P.

The armature A acts upon the principle of the Wagner Hammer, and the continuous current in the circuit is alternately made and broken by its movement to and from the electro-magnet M. A quenching resistance R is in parallel to the electro-magnet M, to prevent any sparking at the contact K.

The rapidity of the interruptions of the current can be varied by means of the screw to the right-hand side of the diagram and above in the illustration, which increases or decreases the distance

through which the armature A moves, and hence decreases or increases the frequency of interruption, or by the screw to the right in the illustration, which increases or decreases the tension of the armature. The circuit under test is thus excited by shocks which have the same frequency and damping as oscillatory currents actually received from a wireless transmitter. The frequency of the interruptions causes an audible note analogous to a received signal from a Quenched-Spark transmitter, namely, a note of frequency 1000.

The electro-magnet windings are wound for the particular purpose for which the buzzer is intended; for example, to test circuits having a resistance of from 0 to 10 ohms, the magnet windings should be about 5 ohms.

Such buzzers working from two small dry cells can be used to excite a ship's aerial, and with careful adjustment have given signals, audible upon a Universal Receiver, up to as far as twelve miles.

The use of a buzzer for receiver testing is universal with all systems of wireless telegraphy. In addition to that just described, which shows the general arrangement of all buzzers, many other types are manufactured for use with Quenched-Spark stations. Other wireless companies have similar modified types.

For commercial work, where the instrument may not be able to be easily repaired, as on a vessel at sea, or at an isolated land station, a very rugged form, such as that just described, must be supplied.

For lighter amateur work, many electrical dealers supply cheaper types, and indeed, if necessity warrants, the electro-magnet of an ordinary electric bell may be perfectly adapted for use as a buzzer. This had its humour in the early days of the war, when under the Defence of the Realm Act very heavy penalties could be imposed for unauthorised possession of a wireless buzzer, whilst exactly similar apparatus was exposed for sale, as electric bells in electrical dealers' windows.

THE CALL-SIGNAL APPARATUS.

One of the most important requirements at a wireless station, where a permanent watch is not kept, is a means of attracting the attention of the operator when he is not listening for signals, this being of special importance for the reception of distress signals from vessels.

For reception the telephone has proved itself the most suitable, and has, therefore, come into general use. When, however, it has been attempted to receive signals on a Morse inker or to use relays capable of ringing a call bell, difficulties have

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FIG. 60 a.—Call-signal apparatus.

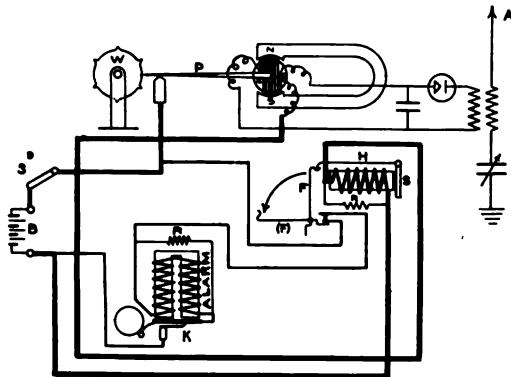


FIG. 60 b.—Connections of call-signal apparatus.

[To face p. 137.



been found, especially as the detectors, which are most suitable for use with a telephonic receiver, are not so good for other purposes.

The apparatus described here and illustrated in Fig. 60 *a* and *b* is arranged to surmount these difficulties.

It is designed for mounting on a table or on the wall, is of small dimensions, and completely self-contained. The ranges at which it is effective, approximate to those which can be guaranteed with a telephone receiver.

The general principle of this apparatus is as follows: A very sensitive galvanometer of high resistance with a light balanced pointer is used to give the necessary contact, and to close a local circuit operating a drop indicator F, which in its turn closes a circuit through a bell. By this means the bell is left ringing until the indicator is restored to its position. It will be seen in Fig. 60 *b* that the principle is extremely simple, but special designs were necessary in order to obtain the desired degree of sensitiveness in the galvanometer and the necessary certainty in the contacts which it makes.

As regards the first, it must be remarked that the galvanometer is suitable only for use with continuous currents or rapidly interrupted uni-directional currents of high periodicity. Rectified currents, as obtained by use of a crystal detector, must therefore be supplied to the instrument, and to these it is extremely sensitive, the throw of the needle increasing gradually for several seconds if the flow of interrupted current is maintained. The galvanometer, therefore, acts to some extent as an integrating instrument, collecting and accumulating any received impulses.

The total motion of the end of the pointer is only one or two millimetres, and it is clear that the pressure which could be obtained against a fixed contact would be quite insufficient to reliably close the local circuit. For this reason a clockwork mechanism W (Fig. 60 *b*) is supplied, arranged to firmly press down the pointer P on to the fixed contact every ten seconds, provided the pointer has moved within reach of the spurs of the pressure wheel. In this manner a thoroughly reliable contact is obtained without at all interfering with the sensitiveness of the galvanometer.

Referring to the photograph a key for winding up the clockwork will be seen, terminals for connecting it up to the local battery and the telephone terminals of the receiver. Below these terminals is an adjusting lever, by which the sensitiveness of the galvanometer needle can be adjusted, and on the top of the box

is a knob, by turning which the pointer is released and the clockwork started again after a call has been received.

The operation of the apparatus is as follows: The sending station which desires to call must send a long signal of at least ten seconds' duration, which is intercepted by the receiver in the usual manner. This causes the pointer P of the galvanometer G to move gradually to a position under the pressure wheel W, and the next time a tooth comes into operation the pointer is pressed against the contact, this making the local circuit indicated by the heavy lines. The current in this circuit actuates a solenoid which attracts the armature S and causes the fall of the shutter F, by its release from the catch H. The fall of F causes two contacts to complete the bell circuit, shown by the light lines. The bell alarm continues to ring until the operator replaces the indicator. After having received the message, the operator releases the clockwork, and the apparatus is once more ready to receive a call.

For use on board ship, to neutralise disturbance to the galvanometer needle due to rolling, the apparatus is mounted on a Cardanic suspension.

Much propaganda material has been published in the recent daily press regarding a "new invention" which is "an apparatus which will permit of a ship in distress to call other ships even when the operators are not on watch".

The author first used the apparatus just described in 1911, and therefore awaits with interest further developments of this recent discovery.

Certainly the old apparatus can be made much more reliable by the obvious application of larger currents from the modern valve intensifiers, and he understands a new Quenched-Spark Call-Signal Device is now being produced on this principle.

The form of apparatus already described worked admirably on land. At sea, owing to the rolling of the vessel causing movement of the galvanometer pointer, false alarms could not be altogether avoided, unless as already mentioned, a special Cardanic suspension was used.

The Detector-Testing Apparatus.—For the testing and adjustment of a large number of detectors after manufacture, it is necessary to have some convenient method of producing signals, and so to obviate dependence upon signals from transmitters out of direct control. For this purpose a special apparatus, shown in Fig. 61 *a*, is used. This consists of circuits as shown in Fig. 61 *b* excited by a buzzer B, from cells by means of a switch.



FIG. 61 a.—Detector-testing apparatus.

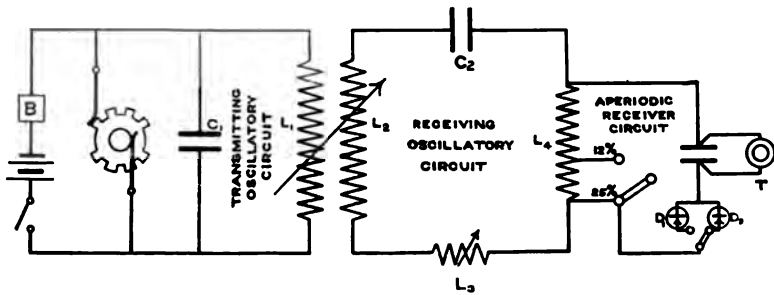
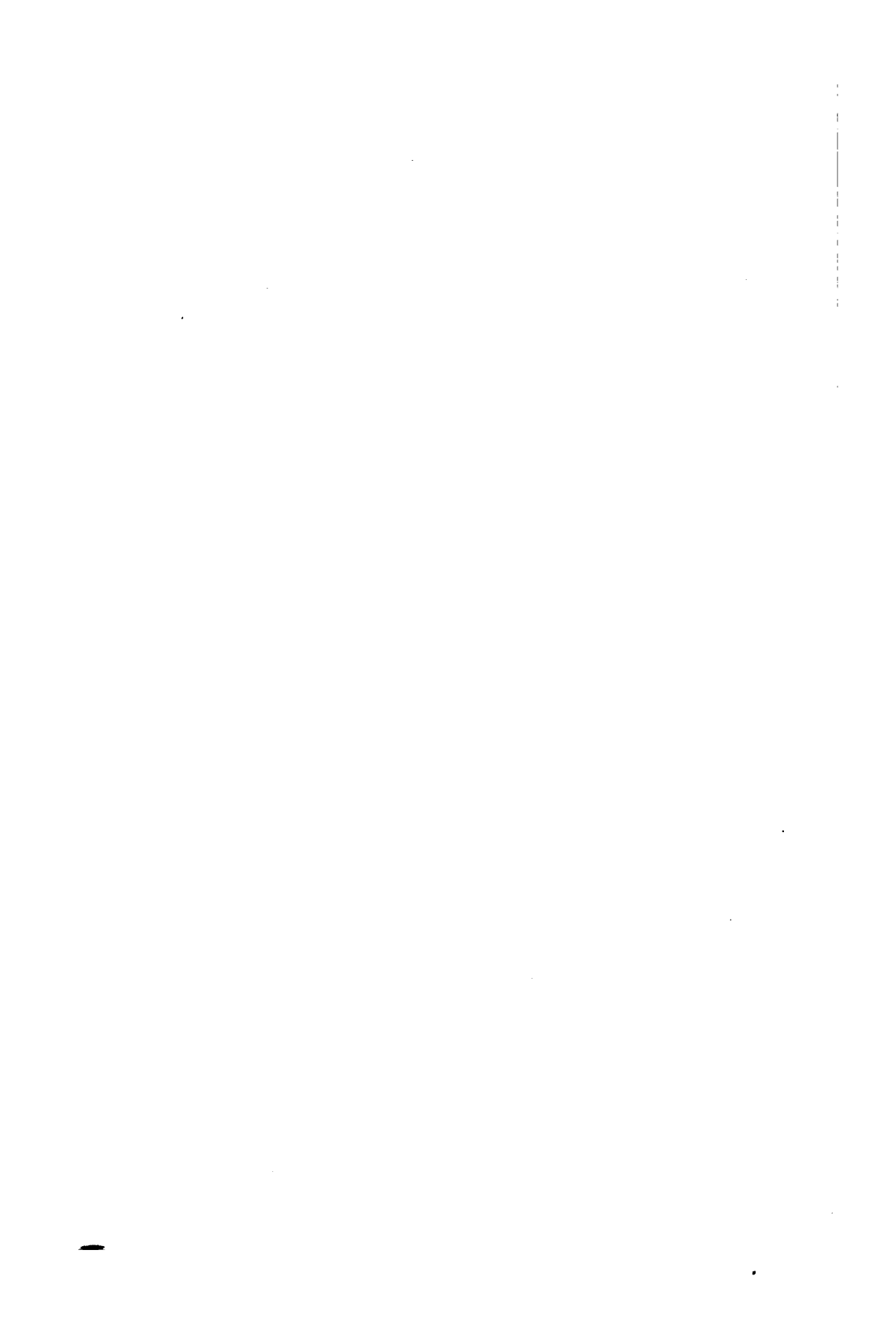


FIG. 61 b.—Connection of detector-testing apparatus.

[To face p. 138.]



The buzzer circuit has a capacity and inductance giving a wavelength of 600 metres, and induces upon a second circuit. The coupling between these two circuits may be varied by means of a rotating handle working a variometer inductance L_2 . The second or intermediate circuit is also oscillatory, and its period may be varied by another variometer L_3 . By means of a direct coupling L_4 , this excites a detector circuit having a condenser, across which a telephone is shunted, and two detectors D_1 and D_2 , either of which may be used by means of the switch.

To test a detector with this apparatus it is inserted in the socket at D_1 and a standard detector inserted at D_2 . The intermediate circuit is now excited by the buzzer circuit by closing the battery switch, and the variometer L_1 L_2 is adjusted until maximum sound is heard by the standard detector. The reading of the variometer L_3 is then taken, and the detector to be tested is put in circuit and a similar reading taken. These readings, which are in degrees, then show the relative sensitiveness of the detectors. As, however, between two different forms of detector it is necessary, for comparison, to take into account their particular coupling, a switch is provided which varies the direct coupling between the detector and intermediate circuits from 15 per cent. to 25 per cent., this making the necessary corrections for detectors of the standard Telefunken types. For comparison of similar detectors either coupling can be used at will.

In addition to the buzzer, which is enclosed upon a cushion in a round metal case plugged into the top of the apparatus, a clockwork mechanism is provided, which, if plugged into particular sockets, sends ordinary Morse signals of the letter V. This is obtained by the clockwork having a wheel with appropriate notches cut, which, as it revolves, makes contact and short-circuits the buzzer corresponding to the intervals between the dots and dashes of the letter V.

A second pair of telephone sockets is provided in the buzzer circuit to test whether it is working correctly if signals are not received with the detector which is being tested.

To test electrolytic detectors a special pair of plug sockets connections for the detector circuit are used having a small switch to put the actuating battery required for this type of detector in or out of circuit. This is seen in front of the apparatus in the illustration.

In using this apparatus it must be carefully borne in mind that the sensitiveness of different types of detectors varies with the applied auxiliary e.m.f. (if this is used), the coupling and the resistance of the telephones.

In making comparisons of different types of detectors with this apparatus, it must, by means of the accessory plug already mentioned, be arranged to apply that e.m.f. most suitable for the particular detector. Also two telephones should be used alternately, one standard and one having a variable resistance in its leads. Finally the coupling must be varied.

In practice, however, it is more economical to restrict telephone resistances to a few selected values, and the Quenched-Spark system select detectors which work best with such standard telephones and which do not require any auxiliary e.m.f. Hence in practice the above apparatus gives very reliable and rapid manufacturing tests, where extremely accurate comparisons of sensitivity are not desired.

The Double-Receiving Switch.—Before the advent of this apparatus it was impossible at one station to receive two different telegrams at the same time except by using two different antennæ.

The Telefunken Company succeeded in the year 1900 in receiving two different messages on one aerial by means of tuning of two receivers connected in parallel to each other, but having a common aerial. This was of little practical importance.

The basis of every method of double-receiving is a difference in wavelength (apart from the possibility of separating two messages by difference in tone, which has now been made possible) by the use of the musical spark.

Every antenna can, owing to its electrical properties, only receive one wavelength efficiently. The reception of two messages on one aerial by means of "selection," i.e. separation of two different wavelengths is always accompanied by considerable loss of energy, which loss becomes greater the more the intensities of the two messages vary from one another. Moreover, two such receiving systems, being electrically coupled, influence one another to such an extent that it is impossible to make any adjustment to one without upsetting the adjustment of the other.

The Telefunken Double-Receiving Switch is based on an entirely different principle. By means of this piece of apparatus the aerial is connected to first one and then the other of two receivers. This alternation is so rapid that each receiver is connected to the aerial three to four times during the time occupied by a dot in the Morse alphabet. Fullest utilisation, therefore, of tuning can be obtained by this apparatus, and ensures absolute independence of the two receivers. The intensity of the signals as heard in the telephone is hardly affected, since the human ear

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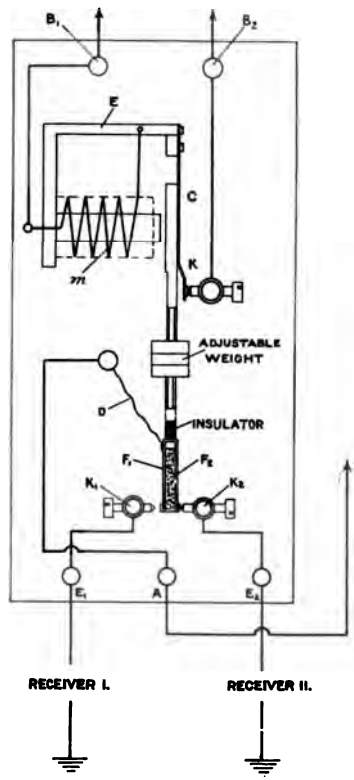


FIG. 62 b.—Connections of double-receiving switch.

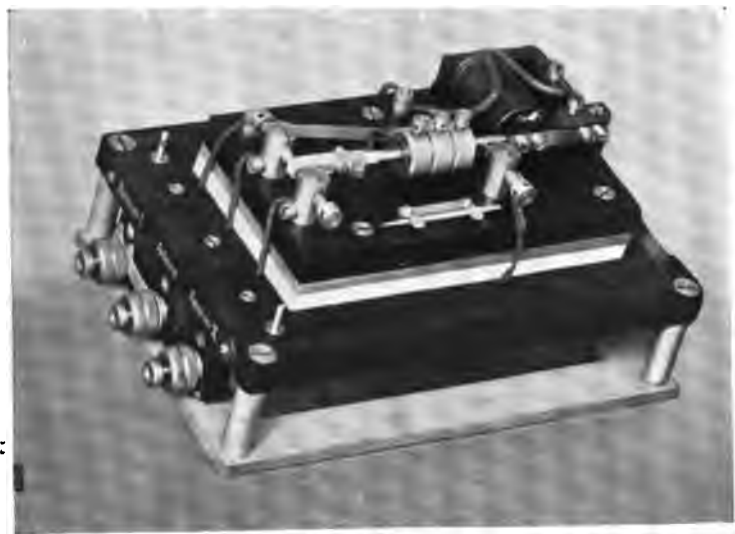


FIG. 62 a.—Double-receiving switch.

[To face p. 141.

reacts not to the momentary effect, but to the total effect, so that with the Double-Receiving Switch almost the same ranges can be attained as when receiving on a single receiver.

This apparatus renders it possible, wherever there is a second receiving apparatus available, to utilise it for the purpose of double-receiving, and the following advantages are so secured :—

1. When trying to obtain the wavelength of a strange station two receivers can be used for the purpose.

2. If disturbances are noticed when receiving, the message can be received on the one receiver, while the other is being carefully adjusted, and the coupling made so loose that the disturbance is cut out. Or, the second receiver can be used to find out who is causing the disturbance and with what wavelength.

3. It is possible at any time, by means of one receiver, to check the adjustment of the other.

4. A station sending, for purposes of secrecy, on two different wavelengths, can be intercepted so that any change-tune device is rendered useless.

Fig. 62 *a* shows the Double-Receiving Switch. The base of the apparatus is an insulating plate supported on four columns. The actual switch is mounted on a similar plate which rests on a sound damping felt pad. The apparatus consists mainly of the tongue of an automatic interrupter. This tongue is provided with adjustable weights, and at the end are two small flat springs on each of which is a platinum contact. These springs vibrate between two contacts mounted on columns fixed to the base of the switch, and their movement is damped by means of felt pads, the springs being separated from the tongue by an insulator. The interrupter consists of an electro-magnet, the armature of which is the tongue referred to above. The tongue can be adjusted to the correct number of interruptions per second by means of the sliding weights. The whole apparatus is protected by a dust and cork-lined sound-proof metallic cover, which ensures the slight sparking of the electro-magnet and does not affect the detectors of the receivers.

In front of the apparatus will be seen at the centre the terminal for the aerial, and at either side the terminals for the two receivers.

At the back of the apparatus are the plug contacts for the battery, consisting of two dry cells. Fig. 62 *b* shows the connections of the Double-Receiving Switch. The current passes from the battery through terminal B_1 , the magnet coil m , the iron

frame E, the armature C, the contact K, to terminal B₂, and back to the battery, so setting the tongue in vibration. The aerial is connected to the middle terminal A, and, by means of the flexible lead D, with the springs F₁ and F₂. The one receiver is connected to the terminal E₁, the other to E₂, terminal E₁ being so connected to contact K₁ and E₁ to K₂. When the apparatus is in use the spring F₁ comes into contact with K₁, and the spring F₂ with K₂, alternately, so that the aerial is joined up to either E₁ or E₂. This alternation occurs about thirty times per second.

To adjust the instrument when the tongue is at rest, the battery being disconnected, the contact K₁ is screwed up to the spring F₁ until it comes into contact with it. This is best ascertained by connecting a telephone in series with a dry cell to terminals E₁ and A. At the moment when the screw K₁ touches the spring F₁ a click is heard in the telephone. The same is then done with contact K₂, the cell and telephone being connected to E₂ and A. The cell and telephone is now connected to E₁ and E₂, and the interrupter started by connecting up the battery to the terminals B₁ and B₂, the motion of the tongue being regulated by means of the contact K. The screws K₁ and K₂ are then carefully screwed inwards until a noise is heard in the telephone, and then screwed back until the noise entirely disappears. The frequency of interruption is then the highest which the apparatus is capable of producing with certainty. The telephone and cell is now connected first to A and E₁, then to A and E₂, and when the sound in the telephone is regular and equally loud in both positions, the apparatus is ready for use.

It should be noted that this apparatus cannot be used for receiving signals from stations working on the old open-spark system unless the spark frequency is at least 50 per second.

High-Speed Automatic Reception.—When using the high-speed automatic transmitter already described it is evident, aural reception being impossible, that automatic means of reception will be required.

The use of such apparatus neutralises errors of reception due to noises in or surrounding the receiving station and also eliminates atmospherical disturbances, since, if automatically recorded, these can usually be easily distinguished from signals. Lastly, in event of any question occurring as to any particular mistake in reception, a printed record is available.

From the point of view of operating, with automatic reception,

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FIG. 63 a.—Photographic high-speed receiver (combined form).

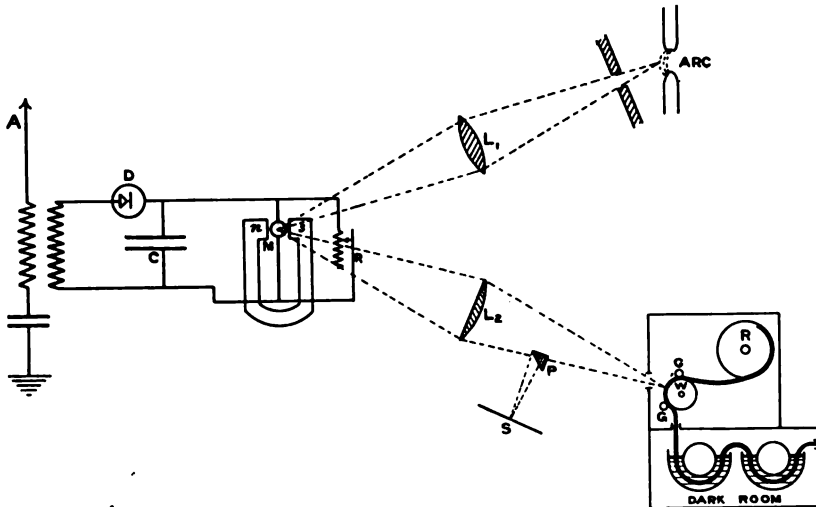


FIG. 63 b.—Connections of photographic receiver.

[To face p. 143.]

the operator is able to give his complete attention to the working of the apparatus. Automatic reception, however, is only available for land stations where disturbing vibrations do not occur, and there is, indeed, no call for it in ship practice.

For such reception there are three chief methods available, in addition to the old coherer and Morse inker, which is not sufficiently sensitive for modern long-range work. These methods are in their order of sensitiveness and speed :—

1. By use of the resonance intensifier with a Morse Inker.
2. By use of the phonographic recorder.
3. By use of the photographic recorder.

The last method is the most sensitive and can obtain speeds varying between 100 to 200 words per minute. The first method, which is also an intensifying method, is described later, and will not be dealt with here.

Both the phonographic and photographic methods cannot be said to belong to any particular system of wireless telegraphy. The differences of various companies' apparatus is that of detail only and not of principle.

Since a beam of light possesses no mechanical inertia, the application of a reflecting mirror to magnify small movements is universal throughout physical science. For example, it is used to record galvanometer movements in most electrical and magnetic measurements, to record movements in rigidity and sound determinations, to record variations in blood pressure in physiology, etc.

It is, therefore, only to be expected that such a useful means of recording would be immediately utilised for wireless recording by many observers in all parts of the world. Doubtless perusal of patent specifications would show numerous patents for such an application to wireless uses, of what is an everyday instrument of ordinary laboratory technique.

The Photographic Recorder or Light Writer.—This method is the most sensitive and rapid method of receiving wireless signals.

The mode of action is to cause the received signals to move the mirror upon a very sensitive galvanometer and so to move reflected light across a sensitised photographic strip.

Different forms of apparatus are made in some of which, for comparatively low speeds, the development of the photographic strip is carried out automatically, and in others, for very high-speed working, the strip is developed by hand.

The arrangement of the apparatus is as follows (Fig. 63 *b*):—

A fine-drawn gold thread, carrying a small mirror, is suspended loosely between the poles of strong permanent magnet *M*, and is in series with the secondary coil and detector *D* of a Universal Receiver.

When a current due to a signal flows through the thread, the latter experiences a force owing to the field of the magnet, and is deflected, so moving the mirror. Light from an arc-lamp is focussed upon this mirror by the lens L_1 , and after reflection at the mirror, is focussed by the lens L_2 on the sensitised strip upon the drum *W*. This slip passes into a dark room, and is there developed, so giving a record of the movement from the rest position of the mirror, and hence of the signals.

A small prism *P* is placed so as to divert part of the reflected light upon a darkened scale in order to render the movement of the thread visible and so control them. Should the vibrations be too great owing to intense signals and cause the light to move off the sensitised strip, they can be adjusted by means of the resistance *R*.

The strip has also to be guided by means of stops in order to keep it in the same position upon the drum. In order to avoid outside mechanical disturbance the galvanometer is often mounted upon pneumatic cushions, Fig. 64 *a*, and enclosed from air draughts, etc.

The arc-lamp works off the same 110-volt direct current supply, as that working the motor rotating the drum moving the paper, the speed of which can be varied by a resistance according to the words being clearly received per minute. Two arc-lamps are provided if the station carries out heavy traffic, in order that no stoppage occurs by failure of the arc.

About 200 words can be recorded upon 8 to 10 metres of strip, and this is developed and fixed during its passage through baths of developing and fixing solution.

The dot and dash signals are recorded upon the slip by variation of the reflected sight from the rest position during the reception of signals.

The galvanometer is mounted upon one stand (Fig. 64 *a*). Upon the other stand, and mounted in a common case, seen to the right, is the arc-lamp apparatus, and to the left the strip-rotating apparatus (Fig. 64 *b*).

The intensities required for various speeds and kind of wave received are given in the following table:—



FIG. 64 a.—High-speed photographic receiver (galvanometer unit).

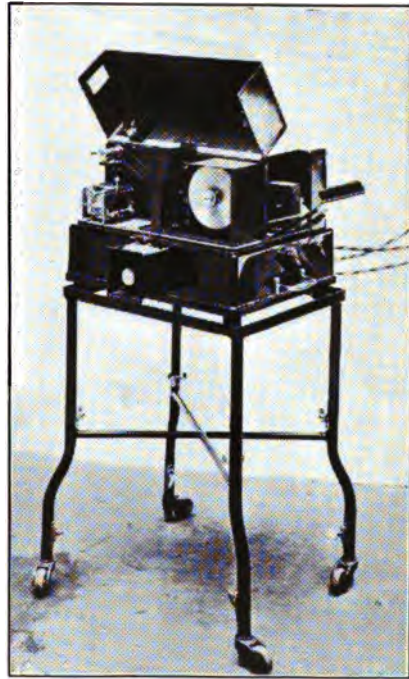


FIG. 64 b.—High-speed photographic receiver (developing unit).

[To face p. 144.]



Spark Frequency.	Velocity, Words Per Minute.		
	50	100	200
	Ohms.	Ohms.	Ohms.
Damped waves 500 per sec.	20	10	5
Damped waves 1000 per sec.	40	20	10
Damped waves 2200 per sec.	40	40	22
Undamped waves	160	80	40

If the received current is intensified by means of the Lieben relay, these intensities, as measured at the receiver by insertion of resistance in parallel to the telephones, may be 1-80 or 1-100 times as small.

The sensitive strip is provided in rolls to last for about twenty minutes' working, and the advantage (as compared with the phonograph receiver) of longer working with one charge is so obtained.

The apparatus last described, from which the sensitive strip passes to a dark room and is there developed by hand, has the advantage over the combined recorder and automatic developing and fixing apparatus (Fig. 63 *a*) of there being no possibility of strip being damaged by a too rapid emergence into the light. Secondly, the chemical solutions are kept right away from the apparatus and so cannot corrode it.

The Phonographic Recorder.—This apparatus is used when it is required to obtain easy manipulation combined with accuracy and high velocity in conjunction with a normal receiver and an intensifying apparatus, such as the Lieben valve.

The intensity of the received signals must be at least 1 ohm for a speed of 15 words per minute and 0.1 ohm for a speed of 100 words per minute. These intensities are measured by the amount of resistance which must be put into parallel with a 1000-ohm telephone just to give audible signals. It should be noted that the greater this resistance, the weaker is the signal, and vice versa, since the high resistance telephone being in parallel with the low variable measuring resistance, the majority of the received current will pass through the resistance and not through the telephone where it is audible. Hence decrease in the measuring resistance means less current through the telephone and for equally distinct signals a greater intensity.

In the phonographic method the receiving telephone is acoustically coupled with a phonographic receiving trumpet.

The phonograph is extremely sensitive, and the drum upon which the message is written is caused to rotate by a small direct current motor, controlled by a regulating resistance marked in words per minute. The record receives an impress of the dots and dashes, and these can be translated by rotating them again at a low speed, such as 30 revolutions per minute, and receiving the sounds by means of a telephone.

Each record will receive about 320 words, and after translation can be re-used, if the dot and dash impressions are removed by rotating the record against a cutter moved uniformly along the record.

In the Telefunken apparatus for reception at 75 words per minute, the record is rotated at 180 revolutions per minute, and for 100 words per minute, at 240 revolutions per minute.

A small switch is provided to start or stop the motor of the record, and it is necessary, before giving a predetermined signal to the transmitting station for it to commence sending, to see that the motor is rotating uniformly at the correct speed.

The method is applicable to ordinary high-speed telegraphy or to wireless telephony.

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FIG. 65 a.—Tone Intensifier.

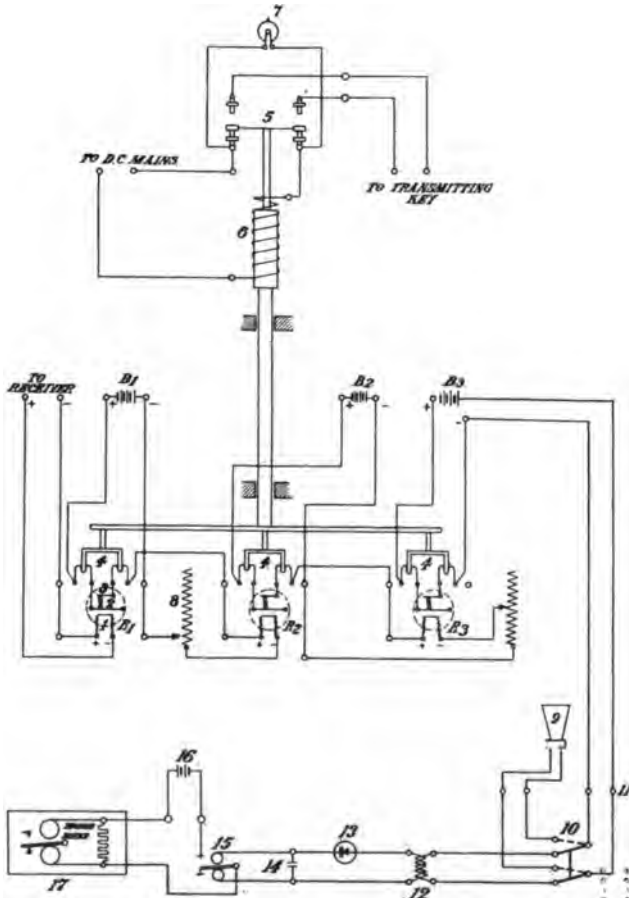


FIG. 65 b.—Connections of Tone Intensifier. [See p. 147.]

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CHAPTER VII.

THE INTENSIFICATION OF WEAK RADIO-TELEGRAPHIC SIGNALS.

PART A.—MAGNETIC INTENSIFIERS.

IT is an important problem in wireless telegraphy to be able, if necessary, to increase the intensity of incoming signals in order to permit them to be read over a longer range.

For this purpose, it is necessary to employ some form of relay, either of the magnetic-microphone type or of types actuated by some special physical phenomenon, the chief of which are of the thermionic type.

One of the earliest practical types of the former class of apparatus was first evolved by the Telefunken Company and developed to the Universal Tone Intensifier (Fig. 65 *a*), so-called because it could be adapted to intensify signals resulting from both damped and undamped oscillations. By means of this apparatus, a received current of, say, 10^{-7} ampere or 10^{-8} ampere, can be increased up to a current of 10^{-2} ampere.

The sensitiveness is high, and by means of this instrument the speed of telegraphing can be raised to the highest rate obtained by handworking or even to that of a Morse transmitter.

A diagrammatic representation of this apparatus is shown in Fig. 65 *b*. It consists essentially of three microphone relays, R_1 , R_2 , R_3 , the principle upon which these depend being briefly as follows: Two carbon surfaces are laid in loose contact and placed in a circuit containing a telephone and cells. There is a resistance at the loose contacts which is extremely inconstant, and varies with the slightest mechanical motion such as that caused by the impact of sound waves. The current from the battery is so strengthened or weakened and causes corresponding changes in the telephone, so that the effect of the disturbing source may be aurally received.

In practice microphones are used having fine carbon powder in place of solid carbon, since the active carbon surface is increased, giving a much increased sensitiveness.

The microphones in the tone intensifier consist of a light armature carried by two steel wires, suspended in front of a small electro-magnet. The armature can be adjusted to vibrate at a definite frequency (viz. 1000 vibrations per second). This adjustment is effected by tightening or slackening the wires which carry the armature.

To the vibrating armature is attached the one electrode of a small carbon-dust microphone, the other electrode of which is fixed rigidly. When the armature is set in motion by currents passing through the windings of the electro-magnet, variations in the resistance of the microphone, and therefore variations of the current in the circuit of which the microphone forms a part, are set up. These variations in the current are of greater intensity than the original impulses in the primary circuit, but are of exactly the same frequency.

The microphones are contained in sound- and water-proof cases. On the covers of the cases are ring-shaped magnets, which can be rotated round the central axis of the microphone. The lines of force from these magnets influence the microphones and permit of a very fine adjustment, which must be carried out, in rotation, for each relay until maximum intensity is obtained. The two ends of the telephone magnet winding are connected to the lower fork-shaped connecting lugs, and the connections from the microphone are led to the upper hooked contact lugs.

The degree of intensification which can be obtained by means of a single telephone intensifier would not be sufficient to render the sounds audible throughout a room. It is therefore necessary to use several. Three such microphones, attached radially to a central casting, are connected in series, so that each intensifies the current of the preceding one.

In order to protect the microphones when transmitting they are disconnected by means of a double-pole automatic switch (5), worked by an electro-magnet (6), and contained in the top of a Cardanic suspension device, fitted in order to enable the apparatus to work on board ship, irrespective of the vessel's rolling.

When the transmitting and receiving change-over switch is switched on to the transmitting position, the electro-magnet is excited and operates the double-pole switch. This automatic switch is connected in such a way that all danger of injury to the windings of the magnet, if it is kept switched on for a long time, is prevented. The method by which this is attained is shown in the diagram of connections. Tracing out the circuit

from the two terminals "to transmitting key" "D.C. mains," it will be seen that the small incandescent lamp (7) is short-circuited. On switching on, the electro-magnet receives the full pressure and attracts the armature, drawing the switch-knives (4) out of the contacts of the microphone switches. As soon as the switch is opened the lamp is automatically inserted in the circuit and the current weakened, so that even if current is on the electro-magnet for hours at a stretch there is no injurious rise of temperature. The lamp is red, and the lighting of the same is an indication that the intensifier is out of circuit and transmission may safely take place.

The electro-magnet serves further to close the low-tension primary circuit of the wireless transmitter, in conjunction with which the tone intensifier may be used. The terminals are on either side of the wooden frame of the apparatus at the top, and by this means it is impossible to send and so injure the microphones, until the intensifier is switched out. In order that the sensitiveness of the microphones may be adjusted, either for the purpose of reducing the effect of disturbance, or because the intensity of the signals is too great, the first two microphones are provided with resistances (8). These are built at two corners of the three-cornered casting supporting the microphones in such a way that only the sliding knobs for adjusting the resistances are visible. When these knobs are in their lowest position the resistances are entirely cut out. It is most important that the resistances should always be put in after the apparatus has been in use.

The intensified current from the third relay may be used to directly work a loud-speaking telephone (9), or by means of a switch (10) a Morse inker (17), so that messages written in Morse code may be obtained.

The loud-speaking telephone is used in order to render the signals audible throughout the room. It is a 25-ohm telephone mounted on a wooden base, in such a position that the sound waves emitted by it do not impinge directly on the microphones. The diaphragm can be set nearer to, or further from, the magnets by merely turning the body of the telephone. By this means it is adjusted to give the maximum sound. An acoustic resonator is fitted in front of the opening, which also increases the sound. When adjusting the apparatus this resonator is moved to and fro until the maximum sound is attained. It is not necessary to adjust the resonator while working, but when the signals become weak an improvement can sometimes be obtained by an adjustment of the distance of the diaphragm from the magnets.

The diaphragm should be adjusted very carefully, as otherwise there is a danger that it may become dented, in which case the efficiency of the apparatus is very much impaired.

Under ordinary conditions the loud-speaking telephone is plugged into sockets marked "Loud-speaking telephone," but if the intensity of the signals is sufficient it can be plugged into the sockets marked "Intensifier". This arrangement has the great advantage that it makes it possible, by putting the switch in a position marked "Inker," to have both the inker and the loud-speaking telephone working at the same time, and so to check the recorded signals by the telephone. If the intensity is not sufficient to make the signals audible by means of the loud-speaking telephone they can still be heard by means of an ordinary 1000-ohm head telephone plugged into sockets marked "1000-ohm telephone". The 1000-ohm telephone can also be used when the loud-speaking telephone is switched on—that is, the two can be connected in parallel. If, however, disturbing sounds are then heard in the head telephone, the loud-speaking telephone is disconnected by withdrawing the plug.

When it is desired to use the inker in order to record the signals, the switch (10) should be moved to the position marked "Inker". The microphone currents are then led to the primary windings of a transformer (12), which serves to cut out any continuous current coming from the last microphone circuit.

The secondary of the transformer is connected in series with a detector (13) and the coils of a polarised relay (15). As soon as the intensifier comes into operation alternating currents are generated in the secondary of the transformer; these alternating currents are converted by the detector into continuous currents and operate the relay. The working contacts of the relay are connected in the ordinary manner in series with the coils of the Morse instrument and terminals marked "Morse battery". In order to protect the detector from injury when transmitting a small mica condenser (14) is connected in parallel. For the high-frequency oscillations this condenser forms practically a short circuit across the detector.

The top of the frame holding the various parts of the apparatus, is made in such a way as to provide against damage due to rolling when the apparatus is used on board ship. The horizontal top of the frame has a spherical hollow space inside, and is lined with felt. On the felt lining rests a small rubber pneumatic cushion, the valve of which projects through the wood in front. The metal frame which carries the electro-magnet and

supports the intensifier microphones is of spherical form underneath and rests on the pneumatic cushion. By this means the whole apparatus is enabled to maintain its vertical position, even when the ship is rolling, and shocks and vibration do not reach the microphones. In order to prevent the possibility of the swinging apparatus striking the wooden frame during severe rolling, several leather pads are fitted to the back of the frame at a suitable height.

An accumulator battery, with three single accumulator pairs, each of 4 volts, supplies the necessary current for the intensifier. For a station working twelve hours per day the batteries probably need recharging about every third or fourth day. The capacity of each cell is about 6.5 ampere hours. As the third microphone of the intensifier carries the heaviest current (about 0.5 amp.), the third cell of the battery would always be discharged much more quickly than the others. To equalise the discharge it is well to exchange the plugs connected to the battery frequently.

The following interferences are often experienced when using this apparatus.

If the intensity is too great the note becomes impure. In this case the coupling of the receiver should be loosened until the note becomes pure. Under the same circumstances the Morse inker would also produce faulty signs.

If the vessel on which the intensifier is erected is subjected to violent shocks and vibration, as is often the case on torpedo boats, accidental sounds which may be produced by the telephone can be prevented by inserting resistance in the microphone circuits. This, of course, at the same time decreases the sensitiveness of the whole apparatus, and the resistance should be cut out again as soon as the cause of the disturbance has ceased.

If signals are received from several stations working with musical notes of the same wavelengths, but with different spark frequencies (e.g. 800, 1000, and 1200 per second), it is possible to get rid of the disturbances due to the stations working at 800 and 1200 per second by coupling the receiver very loosely. The intensifier will then strengthen only the signals from the station working at 1000 per second, and owing to the weaker intensity and difference in note, no disturbance will be noticed from the other stations. Any difference in frequency between the note of the transmitting station and the note to which the intensifier is tuned, will reduce the sensitiveness of the intensifier, and the greater the difference is the more the

sensitiveness will be reduced. The maximum degree of sensitiveness can only be obtained with perfect resonance.

The tone intensifier can be used for continuous wave reception, if these are first rendered of audible frequency by means of some form of tikker as described under wireless telephony.

This form of intensifier whilst largely superseded at the present day by valve intensifiers is however by no means out of date, since such forms of magnetic relays, whilst less sensitive than the valve type, are much more reliable in the hands of the average operator, offers much easier manipulation, and is more robust.

Eccles who has apparently seen the example at Woolwich speaks very highly of this relay, which he states can be heard all over a large room. The author, with weak signals, has been able to normally obtain signals strong enough to be heard in the open air of a noisy factory yard up to about fifty yards' distance.

The only other common type of magnetic relay is that of S. G. Brown, which the author had the opportunity to use in France. The author can speak highly of this small and reliable relay, which is made up so that in size it is much more convenient than the large Cardanic suspension of the Telefunken intensifier, although doubtless for reliable working on board ship, for which the latter is intended, it would be necessary to mount the Brown relay on some similar form of Cardanic suspension. This relay is shown in Fig. 66 *a*.

A brass cover, which is not shown, is secured at the base by four screws, the upper half is hinged and may be opened to get at the instrument. The reed P is adjusted towards, or away from, the magnet H, by turning one or other of the holding-down screws Y. It is important that the reed be set as closely to the magnet as possible, and that the space between it and the magnet be clear of iron filings or dirt. When in this condition, the slightest pressure will make the reed collapse towards the magnet, but this can be prevented, if necessary, by placing a double thickness of tissue paper loosely in the gap, under the reed.

The contacts M and O are of iridium and hard carbon respectively. The top contact M is bluntly pointed and screws into the coarse adjusting screw J; it rotates out of centre, so that fresh points of contact may be obtained whenever necessary. The lower contact O of carbon is flat and screws into the reed P. Both contacts should be highly polished, be worked dry, and be cleaned occasionally by a dry cloth or piece of paper. If desired,

both top and bottom contacts may be of iridium, but in this case they should be worked under oil, by applying a small drop of thin sewing machine oil to the lower contact before lowering the top contact into place (see Fig. 66 b). The top contact is carried by the hinged arm L, which arm may be tilted back to clean the contacts.

The contact pieces are opened to an infinitesimal degree,

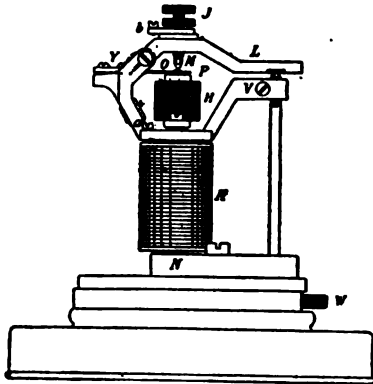


FIG. 66 a.—Brown relay.

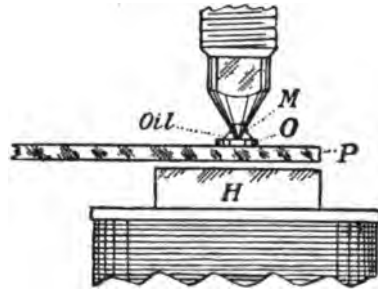


FIG. 66 b.—Contact of Brown relay.

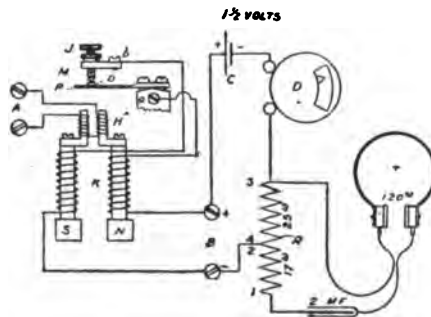


FIG. 66 c.—Internal connections of Brown relay.

by the fine adjusting screw J, to form the microphone by the action of the local current, which passes through the contacts and the self-regulating winding K. The local current thus assists to form the microphone and to keep the instrument in adjustment. The value of the local current through the contact and round the circuit is regulated, by turning the fine adjusting screw, by means of the milled head J. The local circuit of

the relay is joined through the battery C, milli-ampere-meter D, and auto-transformer R.

A 2-M.F. condenser is included in the circuit of the telephone headpiece T to exclude the steady current; the auto-transformer and condenser are mounted and connected together on a board called the "transformer board".

The telephone headpiece may be connected directly in the local circuit, if desired, and the transformer board dispensed with, but in this case the best resistance for the headpiece is 40 ohms.

With a crystal detector the resistance of the A winding of the relay is the standard one of 4400 ohms.

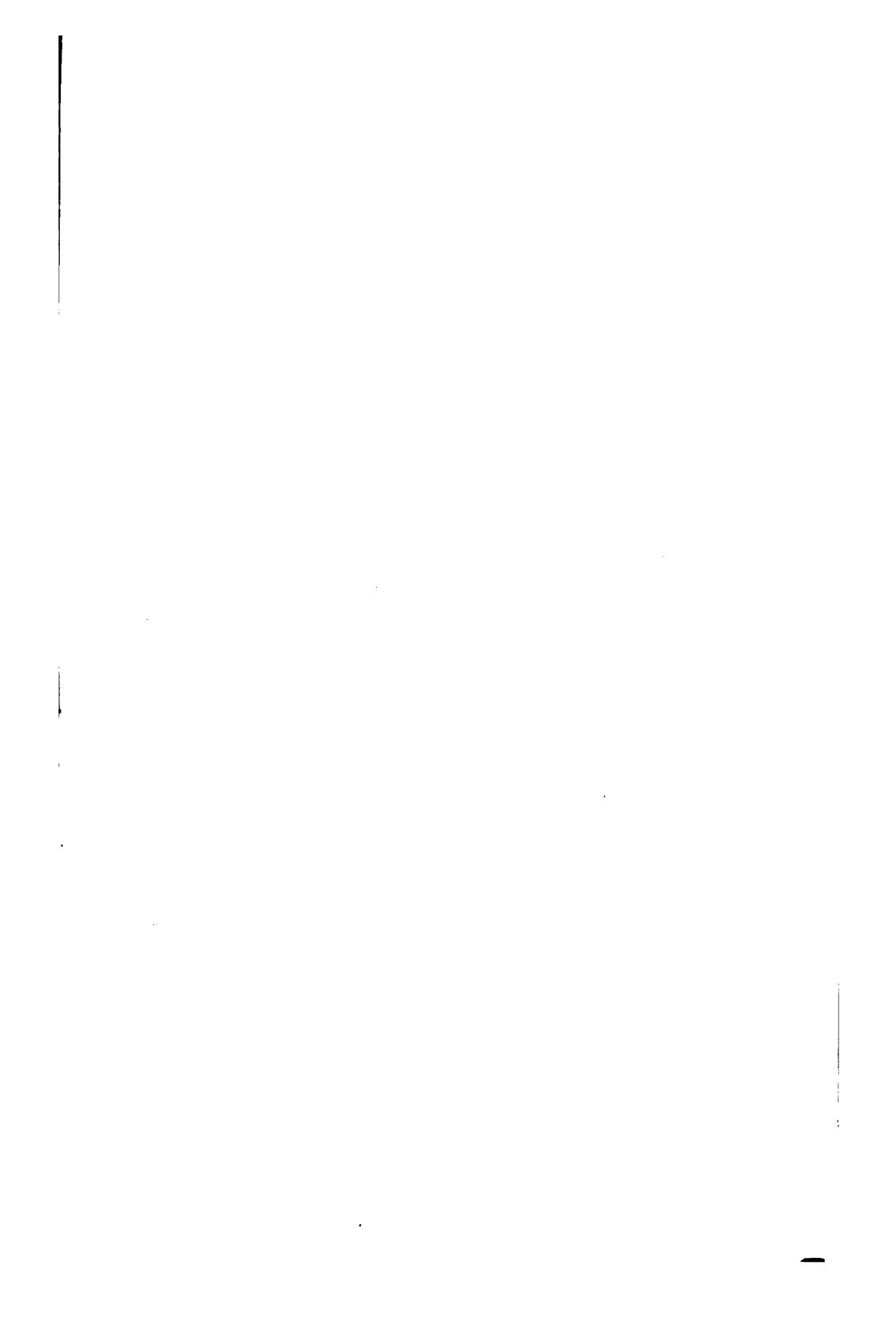
Across the A winding is placed a plug condenser which has a variable capacity of from '0025 to '01 microfarad. The amperemeter D of low resistance reads up to 50 milli-amperes. The telephone headpiece T should have a resistance of about 120 ohms and be connected to the transformer board by the terminals marked S. The relay should be adjusted till the amperemeter shows a reading of from 8 to 12 milli-amperes, when it should be in its most sensitive condition.

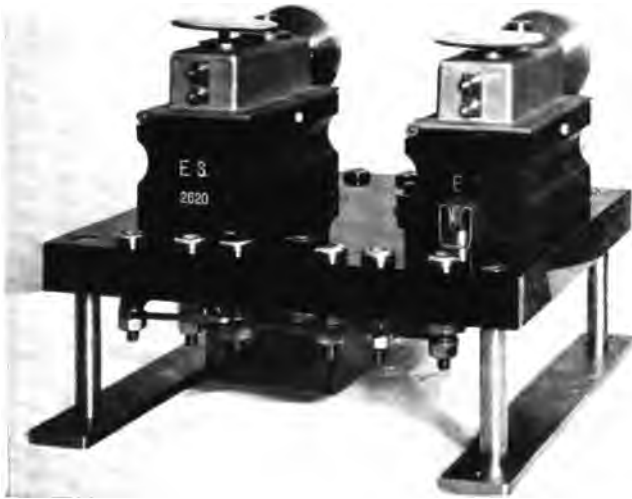
If the relay gives an occasional bubbling sound in the telephones, it is necessary to tap the base of the relay, or to momentarily short-circuit, with a piece of wire, the P terminals of the transformer board. The sound is only liable to occur with the iridium contacts when the instrument is freshly set up. If the relay does not show sufficient sensitiveness, move the adjusting screw head J or tap the base. If this is not sufficient, the contacts should be cleaned and inspected for correctness of adjustment.

If the relay is subjected to vibration the effects can be minimised by standing it on soft rubber corks or a cotton pad, or, if the vibration is severe, a special anti-vibration case can be supplied. In such an anti-vibration case it is difficult to adjust the relay unless the instrument is provided with an auxiliary winding for a distant electrical control.

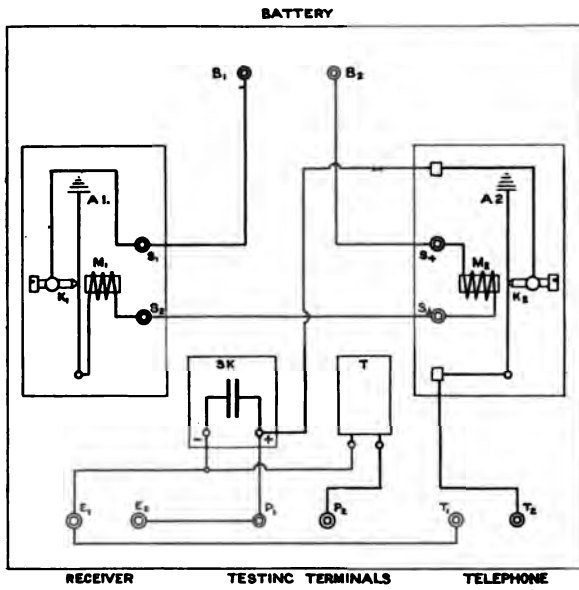
The Tone Converter.—The resonance curve for a Telefunken Tone Intensifier already described is shown in Fig. 67.

It will be observed that maximum intensity is obtained, when the signals to be received, have the frequency of 1000 per second (as in the case of Telefunken stations), and at the frequency of 700 and 1300 the intensification is practically nil. In order to be able to intensify such signals, and those without these limits, an auxiliary apparatus, the Tone Converter, may be employed.





a.



b.

FIG. 63.—The Tone Converter.

[To face p. 155.]

This makes the intensifier applicable for use with both damped and undamped (continuous) waves of any frequency.

The Tone Converter is connected between the receiver and the Tone Intensifier, and transforms the tone of the received signals to the tone which is most suitable for the Tone Intensifier. It is practically a special form of "tikker".

Fig. 68 *a* shows a complete Tone Converter. Two tuned buzzers are mounted on an insulating plate, which is raised on four short columns. The left-hand one of these two buzzers

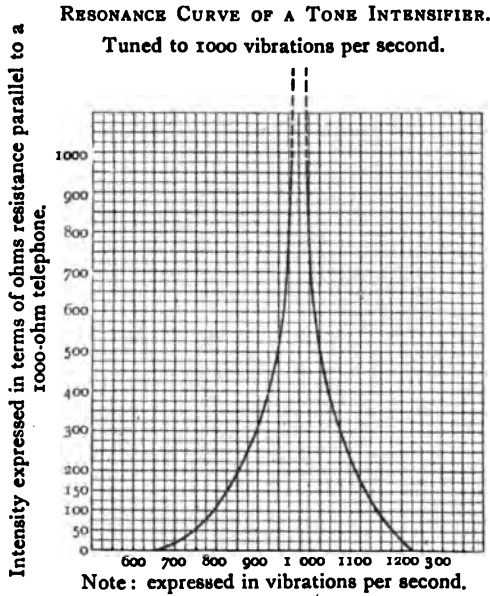


FIG. 67.

produces interrupted continuous-current impulses (1000 vibrations per second); the right-hand one serves to interrupt the receiver current at the same rate, viz. 1000 times per second.

Fig. 68 *b* shows the connections of the Tone Converter. The working current from the battery flows through the contacts B_1 and S_1 , across the working contact K_1 of the left-hand buzzer through the magnet coil M_1 of the same, over the socket S_2 to the socket S_3 of the right-hand buzzer, through the magnet coil M_2 of this buzzer and the socket S_4 and back to the battery.

On the front edge of the insulating plate is seen from right to left plug sockets (T_1 and T_2) for the telephone or Tone

Intensifier, testing terminals (P_1 and P_2), and plug sockets (E_1 and E_2) for the receiver.

At the back of the plate are the sockets B_1 and B_2 for the actuating battery (dry cells), and underneath the plate is a collecting condenser SK and testing cell T.

In this way the left-hand buzzer is set in operation and causes the adjustable tongue A_1 of the left-hand buzzer to vibrate. This gives rise to pulsating direct currents in the circuit described above, the impulses being of the same frequency as the number of vibrations of the tongue A_1 . These pulsating currents flow through the magnet coil M_2 , and give rise to an alternating magnetic flux in the iron core, so that the tongue A_2 of the right-hand buzzer also vibrates at the same rate. The tongue A_2 will vibrate with the greatest amplitude when it is tuned to exactly the frequency of the alternating field of the iron core; that is, to the frequency of A_1 .

By the vibrations of A_2 the contact K_2 is opened and closed with the same frequency as the vibrations of A_1 , so the energy which is stored up in the collecting condenser SK can discharge, over contact K_2 into the terminals of the telephone (or Tone Intensifier) T_1 and T_2 .

The condenser receives its charges from the receiver as soon as the detector is excited by waves. The Tone Converter can be used only with contact detectors which convert high frequency oscillations into continuous current without the assistance of an auxiliary battery.

The mode of actual working is as follows: The left-hand buzzer is tuned by means of a tuning fork for 1000 vibrations, or for the tone to which the intensifier is adjusted.

The contact K_2 is then screwed back from the tongue A_2 , and the latter tuned exactly to the tongue A_1 . This tuning is easily effected by listening closely to the buzzer, when it is easy to tell when the adjustment is correct.

A telephone is then connected to T_1 and T_2 , the test contacts P_1 and P_2 are connected with the hand, and the contact K_2 screwed nearer to the tongue A_2 until a pure tone is heard in the telephone. If, when the contact K_2 is brought up to the tongue A_2 , the note is not immediately quite clear, this is corrected by a slight adjustment of the tongue A_2 , or of the contact screw.

The receiver is now connected to the terminals E_1 and E_2 of the Tone Converter and excited by means of a station tester or buzzer, and the tone tried by listening to the signals

in the telephone. If the Tone Converter is correctly adjusted, there should be little or no difference in the intensity of the signals, as heard with and without the Tone Converter.

The difference in intensity will become greater, the more the spark frequency of the signals to be received varies from the frequency to which the Tone Converter is adjusted, viz. 1000 per second.

If the frequency of the impulses to be received falls below 500 per second, the conversion to 1000 per second is only effected with considerable loss of intensity.

PART B.—THERMIONIC INTENSIFIERS.

The magnetic intensifiers already described, whilst very rigid mechanically and very reliable in working, suffer from the disadvantage that, for repeated intensification, more or less distortion of the received signals occurs, owing to magnetic lag.

They are also intensifiers pure and simple and not detectors, i.e. they do not rectify oscillatory currents. Before they can be used to intensify signals, previous application of some form of rectifier, usually a crystal, is necessary. For continuous wave signals, they may be used in conjunction with a "tikker" or "tone-wheel".

The thermionic valve intensifiers about to be described, are of more modern origin. They have the great advantages that, by their use no distortion of signals occur, as with magnetic intensifiers, and with slight modification they can be used, not only as intensifiers, but also as detectors for both spark and continuous-wave signals.

More recently still they have been used as a source of oscillatory currents for wireless telephony.

Elementary Principle of the Thermionic Valve as an Intensifier.—As a first conception of a thermionic valve we may say that, in general, it consists of a more or less evacuated tube containing a cathode K (Fig. 69), anode or "plate" A, and an auxiliary anode or "grid" G.

Across the cathode and grid a high-tension circuit V, is adjusted, through which, normally, only a small current flows.

If we insert a suitable milli-ammeter in this high-tension circuit and plot current against variation of voltage we obtain a curve or "characteristic" of the form shown in Fig. 70 on p. 158.

Inspection of this curve shows that, whereas up to the point A the variation of current with potential is relatively the same, when this point of the curve is reached, a relatively small increase of voltage causes a very large increase of current, which occurs until the knee of the curve is reached at B.

If now in the gaseous portion of the circuit V within the tube, we insert a second anode or grid G, which is subjected to variations of voltage v , due to received wireless signals from an aerial, it can easily be seen that, if the V circuit is adjusted to the steep portion of the curve, small variations of the v circuit will set up very much larger variations in the V circuit. Sounds heard in the telephone T will so be much intensified. Furthermore, since the relaying action is not essentially magnetic, the current variations in the V circuit will be absolutely synchronous with those in the v circuit, the oscillations in which have a "trigger-like" action on those of the V circuit.

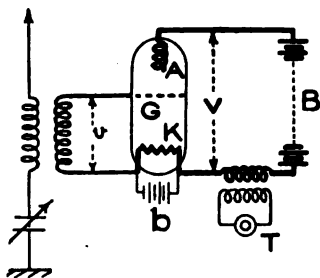


FIG. 69.

There are two methods by which currents can be still further intensified.

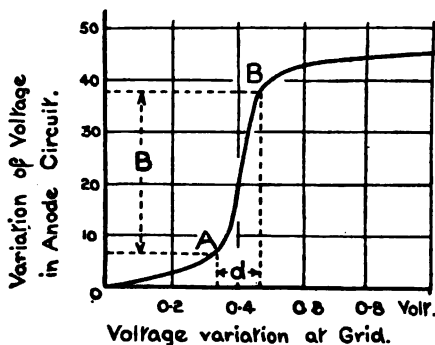


FIG. 70.

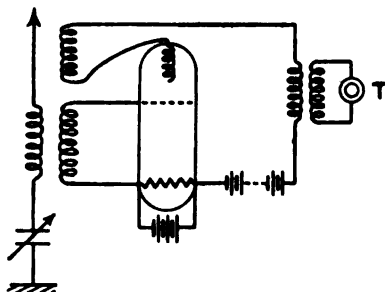


FIG. 71.

In the first method a second valve is used in which the v circuit of this valve is formed by the V circuit of the first valve, i.e. variations of potential in this circuit are caused to vary the potential between cathode and grid of the second valve.

This method of intensification may be in theory repeated indefinitely. In practice a limit is soon reached, whereby sounds, due to other than wireless signals, become relatively so intense and disagreeable that no advantage is obtained.

If a series of such valves are by suitable connections arranged to work from common high and low-tension batteries, they are said to be "in cascade".

The second method of further intensification does not necessarily require another valve. This is obtained by inserting in the V circuit an inductance, which forms one winding of a transformer the other winding being formed by the v circuit (Fig. 71). The original current variations in the v circuit, as before, set up corresponding variations in the V circuit, and these, through the transformer, then set up much greater variations in the v circuit. The process, known as "retro-active coupling," is therefore progressive, the only limit being due to the physical characteristics of the valve electrodes and their capacity to carry the currents.

The energy is, of course, obtained from the high-tension battery, i.e. whilst with retro-active coupling more intense signals may be obtained with a single valve, the high-tension battery gives greater energy and does not therefore last so long.

The nature of the coupling of the grid circuit to the aerial is immaterial, and it may be either direct coupled or magnetically coupled. The Marconi Company would appear to favour direct coupling which gives greater energy transfer at the expense of sharpness of tuning, or selectivity. The Quenched-Spark system would appear to favour magnetic coupling, which gives great selectivity at the expense of energy transfer. Owing to the great efficiency of the Quenched-Gap transmitting stations this is immaterial.

Historical Development of the Thermionic Valve.—The history of the thermionic valve very well illustrates how any present-day scientific progress is not the result of any startling discovery on the part of one man, but is the result of a general trend of scientific work by many observers in many countries.

The investigation of the conduction of electricity through gases was first extensively investigated by Elster and Geitel, during 1882-89.

Hittorf, in 1884, noticed that in a vacuum tube if the cathode terminal was raised to incandescence, the application of a very small e.m.f. caused the passage of a considerable current. The electron theory, having not then been evolved, no explanation was given of this effect, which is the basis of all thermionic valves.

Boltzmann in 1890, would appear to be the first to apply gaseous tubes to wireless purposes, i.e. to detect Hertzian oscillations.

Zehnder, in 1892, improved Boltzmann's arrangement producing his "trigger-tube" (Fig. 72 (1)), in which a local circuit (F.E.G.) was so adjusted that its potential was just insufficient to break down the resistance of a gaseous tube. Complete breakdown resulted when a small additional potential was supplied by an Hertzian oscillator, represented by ABCD. The apparatus was used purely to detect the presence of oscillations, but was undoubtedly also an intensifying arrangement.

Whilst it was not thermionic, i.e. it did not utilise electrons given off from a heated filament, it is undoubtedly more allied to the present-day amplifier in its method of operation than the later two-electrode tube of Fleming.

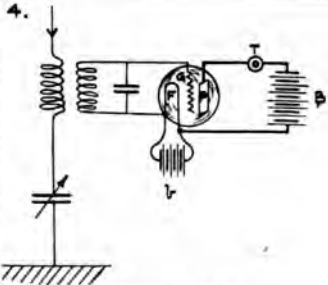
In 1884, Edison, at the Philadelphia Exhibition, had exhibited an apparatus consisting of a plate between the limbs of the filament of an incandescent lamp (Fig. 72 (2)). He showed that if a galvanometer was connected between the plate and the negative end of the filament no current was shown, whereas when the plate and the positive end of the filament were connected, a current was obtained.

Since electrons had not yet been shown to exist no reason could be given for this effect, called the Edison effect, but which had also been independently shown in high vacua, by Elster and Geitel.

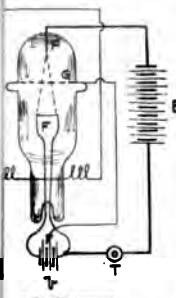
Fleming, in 1904, utilised the Edison effect, and Elster and Geitel's apparatus in a modified form, to produce a wireless detector, rectification being brought about owing to the unidirectional conduction already mentioned. Fleming's arrangement is shown in Fig. 72 (3), and is in effect a reversal of the relative position of plate and filament in Edison's apparatus.

The Fleming valve was purely and simply a rectifier or detector. In no way was it an intensifying device, it did not use a very high vacuum, as is the case in the modern valves of Langmuir and Meissner, and was not a means of generating oscillations like these later valves.

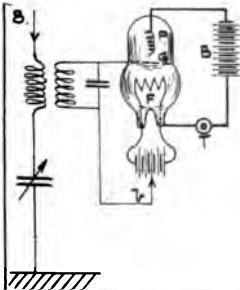
Whilst Fleming must be credited as being the first to apply thermionic phenomenon to wireless detection, the claim that he is alone the originator of the present-day thermionic valve is rather exaggerated, since the intensifying properties of the present-day valve are far more important than its detecting properties, and as an intensifying arrangement, the Zehnder "trigger-tube" is more akin to the modern valve in principle.



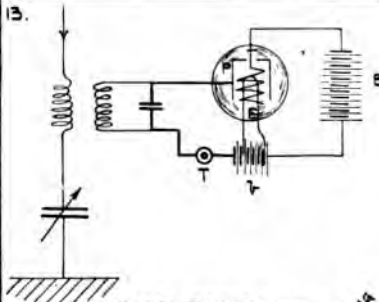
— DE FOREST 1907. —
 (USED AS DETECTOR ONLY, BUT WAS
 UNDOUBTEDLY A RELAY.)



VALVE. —
 ENT 1482.



— LIEBEN REISS VALVE 1911 —
 (ELECTROTECHNISCHE ZEITSCHRIFT.)
 Nov 1911.



— HULL'S DYNATRON —
 (NEGATIVE RESISTANCE) F. A. YOUNG

[To face p. 160.]



11

As a detector the Fleming valve was fairly sensitive, but from the author's own personal experience, a result also noticed by Stanley, it was not so sensitive as a crystal detector. As well as being more sensitive, the crystal detector has the advantage of not requiring any heating battery, with consequent adjustment and maintenance troubles.

The next step in the development was due to de Forest who was the first to use the modern three-electrode valve for wireless work in his "Audion" patent of 1907. This arrangement (Fig. 72 (4)) is essentially the modern valve. It had a vertical filament, a zig-zag grid and a plate, and was certainly a great advance.

As far as the author can ascertain, and certainly from his patent specification, this valve did not, like some of his later ones, use an oxide coated filament. It was a vacuum tube but not of exceeding high vacua. De Forest would appear to have intended his device as a detector only, and did not recognise its possibilities as an intensifier, which it must undoubtedly have been.

Much controversy and litigation occurred over the patent aspects of the audion, Fleming claiming that it infringed his two-electrode valve, although he himself states "the Audion differs from the author's oscillation valve in having a grid and a plate sealed into the bulb, in place of a single metal cylinder surrounding the filament".

The result of this American litigation was that, whereas de Forest was prevented from using his valve, since it infringed Fleming's patent, on the other hand the Marconi Company, who were interested in Fleming's action, were equally prevented in using de Forest's three-electrode valve, which according to de Forest ("Electrician," p. 26, 1916) was their intention.

De Forest's letter referred to above should certainly be read before forming any opinion as to the relative value of claims regarding the origin of the valve. It certainly illustrates how patent litigation can retard scientific progress.

The whole situation regarding this controversy is best summed up in Mr. Justice Sargeant's words at the Chancery Division, on Fleming's application for extension of his 1904 patent: "I should hesitate to describe a three-electrode valve or de Forest valve as being a mere improvement in view of the great independent invention displayed in that device. I do not think that the valve would ever have come into being but for the previous invention of the 1904 Fleming valve, though it is of course obvious and admitted by the Petition, that where the de Forest

valve acts as an amplifier, it is outside any claim on the Fleming valve of 1904."

Considering the great advance due to de Forest, and that all modern valves depend on the audion principle, it is to be regretted that de Forest has received no substantial reward for his patent owing to his voluntarily letting it lapse.

Lieben originally alone, and later working with Reiss, was the next to extend valve development. The original patent (German No. 179,807, and British 1482 of 1911) was an advance in so far that it utilised an oxide coated filament and was described as an intensifier and not as a detector. Later it was used as a detector for both spark and continuous waves, and still later by Meissner to produce continuous oscillations.

This valve utilised an observation made by Wehnelt in 1904, that if a heated filament was coated with certain oxides, such as those of barium or calcium, the emission of electrons was greatly facilitated. For equal emission, a very much lower potential could be used with a coated filament, than was necessary with an uncoated filament, so giving greater sensitiveness and convenience of operation.

As an illustration of how closely progress is related in different countries, one may mention that, in America, de Forest had also tried the effect of coating his filament, but had not had the good fortune to choose the necessary oxides mentioned, whilst in England in 1911, the same year as Lieben's patent, Willows and Hill, in England, had applied Wehnelt's observation to increase the sensitiveness of the Fleming detector.

It is also interesting to compare the evolution of the Lieben valve itself. In 1895, Perrin had used the arrangement shown in Fig. 72 (5) to show cathode rays carried a negative charge, an apparatus later modified by J. J. Thomson in 1897 to calculate the ratio $\frac{m}{e}$ and v for electrons. The original Lieben tube,

Fig. 72 (6), closely followed this arrangement, and consisted of such a tube with an oxide coated filament K, an outer cylinder G, corresponding to the present-day grid, and an inner cylinder P, corresponding to the present-day plate electrode. A high-tension battery was placed across plate and filament, the latter being mirror shaped, so that the cathode rays were brought to a focus at the aperture of the grid and could be deflected from the aperture and therefore from the plate P by a magnetic field due to the magnetic coils of an external circuit. This circuit was entirely distinct from the tube (as was the case in the apparatus

used by J. J. Thomson mentioned above), and could be formed by a wireless receiver circuit. Received oscillations could so be caused to divert the cathode ray beam, and influence the current in the high-tension plate circuit. In the somewhat later English patent the relay was shown as in Fig. 72 (7) in which the two cylinders had been replaced by the present-day anode and grid, but the concave electrode was retained. Connection of the wireless oscillatory circuit to the grid was not yet made, this circuit still being distinct. The final form of the valve is represented in Fig. 72 (8) in which the separate oscillatory circuit was dispensed with, and connection made direct to the grid, a method previously used by de Forest, of which Lieben and Reiss were aware, since de Forest's work is mentioned in their patent specification.

The patent rights of the Lieben valve were acquired by the A.E.G. and the Telefunken Company, the latter company utilising the services of Dr. A. Meissner to investigate the valve's possibilities for commercial wireless work.

Meissner's work resulted in great improvement in the valve; he adapted it for spark and continuous wave reception, and was the first to ascertain that such valves could be utilised, not only to detect and amplify received signals, but also actually to generate continuous wave oscillations.

His early experiments in 1913, resulted in the transmission of wireless telephonic signals over a distance of 35 km., and later in this year he had so greatly improved the valve, that his signals were received in London from Berlin.

The Telefunken-Marconi Patent Exchange having been entered into by these two companies, it is not surprising to find the later company taking up valve work, and it would appear that they deputed Messrs. Franklin and Round to assist Meissner in his researches on their behalf, a fact mentioned by Meissner in the "Jahrbuch der drahtlose Telegraphie," 1919, and Round mentions Meissner's experiments with intimate knowledge in the "Marconi Year Book" of 1915. After the above agreement, a patent for valve reception was taken out in 1913 by the Marconi Company and Franklin, for valve transmission by Meissner in January, 1914, and shortly after (May, 1914) for valve transmission by the Marconi Company.

Meissner originally used the unmodified Lieben valve, but its life for transmission was so short that he modified it to the form shown in Fig. 72 (9), a somewhat simpler design being adopted by the Marconi Company and is well known in England as the "Round valve".

Later work done by Meissner with the original type of valve, in which the vacuum used was not exceeding high and the filament was, as a result, rapidly disintegrated, showed a much longer life and greater regularity of working could be obtained by use of a very high vacuum, not previously obtained in any scientific work, but approached in X-ray tube technology.

He therefore produced the present-day "hard" or high-vacuum valve, a result independently obtained, however, by Langmuir in America, and the French Army Telegraph Service, under the direction of Général Ferrie.

The Round valve was (Fig. 72 (10)) a soft or low-vacuum valve and does not otherwise differ from the Meissner valve, except in minor details of design. As far as the author is aware, Round has never claimed that his valve embodies any special features other than design, and his patent is for the method of connecting circuits to utilise it.

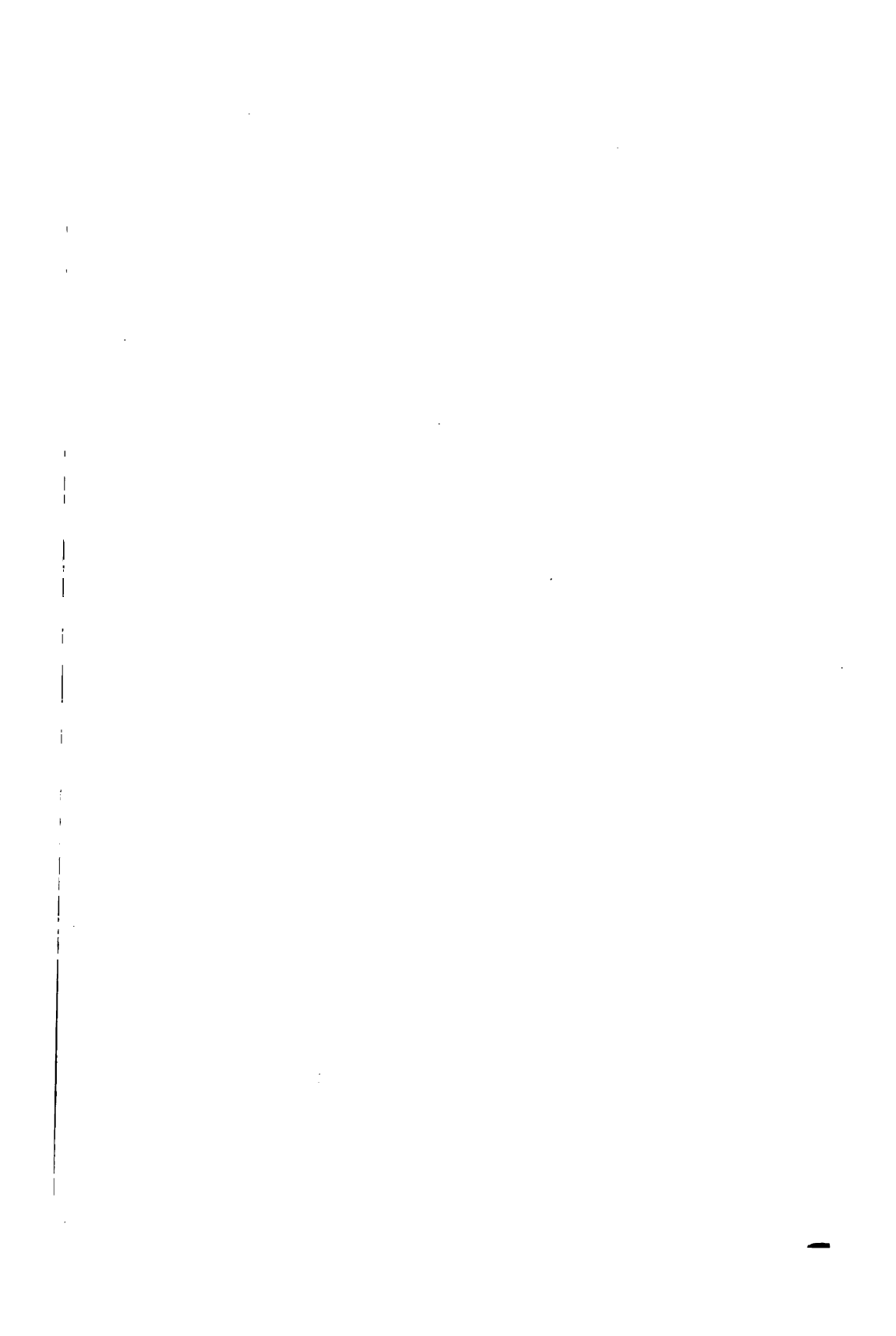
The author after the outbreak of war had very considerable experience in the use of this valve. Its great drawback was that being a soft valve, its behaviour was very erratic. An attempt was made to control this by the introduction of a gas occluding material as asbestos, which on heating gave off gas and on cooling re-occluded it.

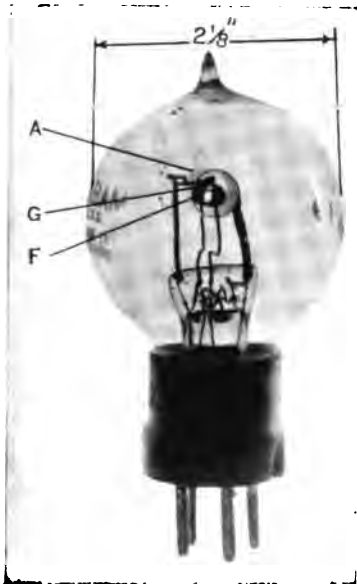
According to Stanley "heating this with a match (i.e. the asbestos) would drive from it gas molecules into the body of the valve, and thus the vacuum could be brought to the proper degree of softness. The necessity of thus regulating the valve was a disadvantage, also the fact that when started up the valve did not come into proper operation for two or three minutes until it became warm, and that the platinum filament was easily burnt out by an improper adjustment of the heating rheostat."

Theoretically it was possible to heat the asbestos by means of a small coil of wire carrying current. Whilst such an arrangement was patented, even the Marconi engineers themselves preferred the more rapid action of a match. The use of a mercury amalgam for this purpose by Lieben and Reiss in their valve was much more satisfactory.

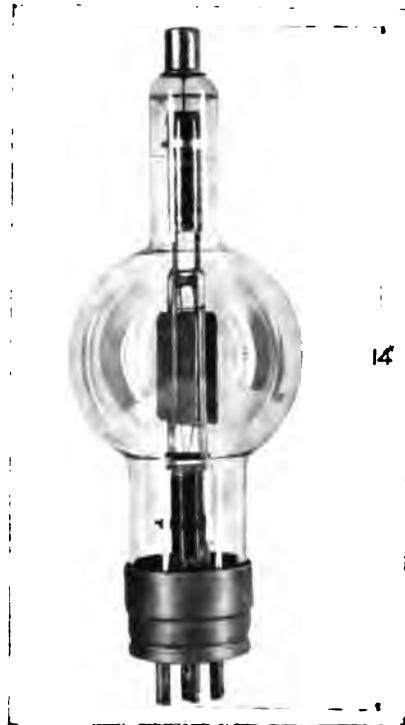
One great objection was that, unlike the Meissner valve, the filament was not stayed off to keep it taut, with the result that in many valves, directly it was rendered incandescent it would sag over, touch the grid and so render the valve useless.

An attempt was made to overcome the short life of the valve, due to burning out of the filament, by manufacturing them with three separate filaments, any of which could be used on choice, or in turn.





(1) French valve.



(2) Langmuir's "Pliotron" for transmission.



(3) Telefunken valve for reception.



(4) Telefunken valve for transmission.

The irregularity of this valve was doubtless largely due in the attempt to make the Lieben form of valve more portable—the great objection to the Lieben valve. This reduction in size made the ratio of electrode area to gas volume much greater, so that any rise of heat in the electrodes had a much greater effect upon the residual gas, resulting in the erratic behaviour already mentioned, an occurrence not experienced in the Lieben valve, since its gaseous volume was very great as compared to electrode area.

A form of soft valve somewhat used in the British Army, known as the "White Valve," retained the relative small electrodes and large gas volume of the Lieben valve, the whole valve being reduced proportionally in order to give a portable valve. Stability was so obtained, but the electrodes being similarly reduced, the current carrying capacity, and therefore possibilities of magnification were likewise reduced. To ensure regularity of action an amalgam was used as in the original Lieben valve.

The French valve, Figs. 72 (12) and 72 *a* (1), already mentioned, combined the advantages of portability, constancy due to the use of a very high vacua, with very rigid design. Its advantages, over other types of valves known in England, were so great that it was most extensively adopted by the British Army, and practically replaced all other forms both for reception and transmission.

The hard valve, evolved by Langmuir (Fig. 72 (11), Fig. 72 *a* (2)) of the G.E.C. of Schenectady, is described in detail later. It is of very large size as it is designed for use with comparatively very heavy currents for transmission work, but may be also used for reception.

At the present day most valves are of the hard type, and the particular methods of mechanical construction are the only differences. It would be impossible to deal with them in detail, and patent specifications must be consulted. One only may be mentioned, namely, Hull's "negative resistance" tube, also described more fully later. This depends on special physical phenomena, and also differs in the receiver circuit being placed across plate and filament, instead, as usual, across grid and filament (Fig. 72 (13)).

The Relative Importance of the Thermionic Valve for Reception.—A perusal of wireless literature in the journals of all countries since 1914, will show that the large majority of attention has been devoted to the thermionic valve, both for reception and transmission.

An observer of wireless progress during this period only, is

likely to draw quite a wrong idea of the relative importance of the valve.

Those having a more extended knowledge of wireless progress will draw a similarity to the period 1906-10, when the Poulsen arc transmitter was heralded as the future wireless transmitter, whereas history has shown that, in comparison to the spark transmitter, it is relatively unimportant.

Whilst the valve, as a detector and amplifier, offers great advantages over the crystal detector, on the other hand, for good working, it requires much greater skill on the part of the operator, and commercially it is even then very much more expensive. In the hands of the unskilled, the question of expense nearly rules it out of practical commercial wireless telegraphy. Similarly for wireless telephonic transmission, whilst the valve transmitter offers great advantages over other continuous wave transmitters for short ranges, the reverse is the case for long ranges.

Undoubtedly one reason for so much attention being paid to the valve of recent years is that previous to the war, as a result of the conservation of wireless engineering into the hands of a very few engineers, it was nearly impossible, without risk of immediate patent litigation, for any person of average means to engage in extensive wireless work. On the outbreak of war the need of wireless officers for military requirements became very serious. In England, particularly, there were very few wireless engineers available. Rather than draw upon trained engineers who had not specialised in wireless and give them the necessary comparatively short training in wireless work, the general policy, until late in the war, was to draw upon purely theoretical physicists. Such personnel was somewhat at a disadvantage in general wireless engineering, since they had no knowledge of practical work, and whilst familiar with laboratory apparatus, were unused to dealing with heavy electrical plant.

Their only recourse was therefore to devote their attention to the valve, which was just then becoming of importance and tended more to reproduce familiar laboratory apparatus. This has led to a large amount of theoretical investigation which, whilst of interest, is perhaps, in practical wireless engineering, of less importance than being able to properly manage an ordinary battery of accumulators, which, whilst simple, can only be efficiently carried out after considerable practical experience.

As a result the theoretical aspects of the valve has been so greatly developed as to overshadow other branches of wireless telegraphy.

If we take three recent papers read successively before the Institute of Electrical Engineers, we find a highly mathematical but none the less interesting paper on the valve by Professor Fortesque, in which the practical aspects are not touched upon, and two non-mathematical papers by Round and Prince, both practical engineers of the Marconi Company, who have done much to introduce the valve into British wireless telegraphy.

To discuss the theory of valves to any length within the limits of this book dealing with general wireless engineering is therefore very difficult, and the subject can only be touched upon. Those requiring theoretical considerations must be referred to papers dealing particularly with valve theory. Those who require a general knowledge of practical wireless telegraphy should carefully remember, that whereas by no means are theoretical papers to be despised, perhaps in this region theory has largely exceeded practice, and the valve has not yet been sufficiently perfected in practice to warrant its being regularly fitted upon mercantile cargo vessels, which carry the majority of the world's wireless stations.

One other aspect of valve work may be briefly mentioned, namely, the large number of "new inventions" which appear in the daily press. These are, in effect, quite old inventions, such as call-signal devices, Bellini-Tosti wireless compasses, etc., in which the very obvious application of the valve receiver in place of the crystal receiver has been applied, with consequent greater sensitiveness.

Non-Mathematical Theory of the Thermionic Valve.—

According to modern physics, the ultimate unit of electrical energy are positive or negative electrons, the movement of which constitute an electrical current.

The work of J. J. Thomson, Rutherford, Soddy, and others, has led to the belief that the unit of chemical matter, the atom, is due to the arrangement of such positive and negative electrons, in a stable formation, that one may compare to the solar system in its orientation.

In some chemical elements, as radium, these minute "solar" systems are in a state of unstable dynamical equilibrium. To obtain a stable condition electrons are thrown off from the system. Such emitted electrons by their movement give rise to waves in the ether known as rays, and the original element undergoes spontaneous disintegration, to eventually form another chemical element, probably lead.

For the large majority of chemical elements, however, the

“solar” arrangement is stable, and its equilibrium can only be disturbed by the application of other energy as heat, ultra-violet light, etc., resulting in the throwing off, or emission of negative electrons.

If, therefore, a metallic wire is subjected to heat, preferably by the passage of a current, electrons will be emitted, an effect well known to many observers, as Elster and Geitel, Edison and others. It is commonly known as the “Edison effect”.

Richardson studied the quantitative aspects of such emission, and for a pure thermionic emission deduced a law that the current c , constituted by the emission of electrons with time, was related as—

$$c = a \sqrt{T} e^{-\frac{\beta}{T}}$$

where t is time, T the temperature, and a and β constants depending on the conditions of the experiment. [Later Richardson modified this to $c = K_1 T^{\frac{K_2}{T}}$, where K_1 and K_2 are new constants.]

Assuming that we could entirely evacuate a tube containing a suitably heated wire, some such law would possibly hold good, and Langmuir is stated to have found that at very high vacua this law is experimentally true.

Absolute exhaustion is, however, still impossible, but during the past few years, since 1915, Meissner, in Germany, and Langmuir, in the United States, have been able to reduce the gaseous pressure to the extremely small pressure due to a height of mercury one hundred thousandth of a millimeter in height, when thermionic emission approximates to Richardson's law.

Such valves pass through a stage of low conductivity and are therefore said to be “hard valves” since for passage of a current, high electrical pressure is necessary.

Previous to the above work, the valves due to Fleming, de Forest, and Lieben (Round) all contained a very appreciable amount of residual gas, which assisted conduction so that passage of current was relatively easy and the valves were said to be “soft”.

With such soft valves, effects other than thermionic emission occur, the chief of which are:—

1. Electrons, already emitted thermionically, collide with molecules of gas, and if they have sufficient velocity, the equilibrium of the gas atom is disturbed, resulting in its being split up into a large positive electron or “ion” and one or more negative electrons.

2. Gas atoms collide with the heated filament and obtain a negative charge. Such collision incidentally rapidly disintegrates and destroys the heated filament.

3. Particularly gases would appear to effect the purely thermionic emission, for example, oxygen causes a decreased emission from a tungsten wire.

4. If the tube containing a heated filament also contains a second conductor, permitting a discharge to be passed between the heated wire or filament, acting as cathode, and the second conductor acting as anode, gas atoms will collide with this anode, obtain a positive charge and be repelled from the anode.

5. Electrons may strike the anode at certain critical velocities, and give rise to an increased number of secondary electrons by impact. This effect was discovered by J. J. Thomson who called the effects, due to the secondary electrons, "Delta rays".

Hull has later utilised such secondary electrons in the construction of a thermionic valve. In soft valves, such secondary electrons do not occur, or if they do, their effects are negligible in comparison to other effects.

Considering the first four effects, we can easily see that the presence of electrons in a soft gas-containing tube will be due to other than thermionic emission. In general the emission will be complicated, and Richardson's law will not hold.

In order to make one factor predominate, so that the others, including thermionic emission, would be relatively unimportant, Lieben and Reiss chose gaseous ionisation, and to promote this introduced vapour, due to an amalgam of sodium.

Round, in his modification of the soft valve, utilised the occlusion effects of certain gases and introduced an occluding substance, as asbestos, which on heating gave off gas, so promoting gaseous ionisation and on cooling occluded gas, so reducing gaseous occlusion. The effects due to such occlusion were very noticeable, but in practice the variations were so rapid that constant attention was necessary to obtain a more or less permanent condition.

Both Lieben and Reiss, and Round, utilised Wehnelt's observation that, if the heated filament was coated with certain oxides, greater ionisation occurred.

In a tube such as we have dealt with in this section up to the present, namely, a tube having a heated filament forming a cathode and a second electrode forming the anode, another factor which may influence conduction is the mechanical configuration of this electrode. In the majority of valves known in England (Round

and French valves) this electrode takes the form of a plate. An objection to such a form is that such a plate occludes gases in its interior, and if, by heavy working, it should become heated, this occluded gas is given off and is a further disturbing factor of the tube's behaviour, since such occluded gas enters into collision with electrons and the electrodes.

The best arrangement of such an electrode is obtained by use of a spiral of wire (Lieben, White, some forms of Langmuir tubes) which, whilst giving large surface area for conduction, has little thickness for gaseous occlusion, so that occluded gases can more easily be removed by methods later described. The anode should, however, be of sufficient size to carry the current to be passed through the tube without overheating, to avoid undue occlusion effects.

Recently Langmuir has adopted a method of forming the plate in which occlusion is overcome. During construction of the tube, even a tungsten filament vaporises and a deposit of tungsten is formed on the glass container. Langmuir's method is to intentionally form a relatively thick deposit in this way, in a high vacuum. Such deposit on the glass walls can then be used as the plate, connection being made by a platinum wire previously sealed into the glass. To overcome the short-circuiting of the filament and grid leads during the process, these are previously shielded by glass, and since the vapourised tungsten particles have a straight path, the deposit does not occur in the neighbourhood of the leads.

In a two-electrode tube the movement of electrons will be proportional to the potential gradient between the electrodes. For example, if no potential exists, emitted ions will describe a parabolic course and possibly return to the cathode. Application of a potential will cause the electrons to follow the lines of force to the anode. The more intense the potential field, the more rapid will be the electronic velocity, until a sufficient number of electrons pass from cathode to anode, to constitute the current which it is possible to pass for a given potential across the electrodes.

With the exception of the Fleming valves, the tubes used for wireless purposes have a second anode, and we must now see the effects produced by such a second anode.

If this second anode were solid, it would, in proportion to its form, entirely prevent the passage of electrons to the original anode, by mere prevention of passage of electrons (Crooke's Tube). If the second electrode is, however, perforated, i.e. "a grid," its

interspaces will, in general, permit of the passage of electrons to the anode or "plate".

This passage of electrons through the interspaces will depend upon:—

1. The potential gradient between cathode and grid, cathode to plate.

2. The size of the interspaces.

Any electron situated in the tube will be partly attracted to the plate and partly to the grid. Its ultimate course will be due to the predominating attraction.

If the interspaces of the grid are small, few if any electrons are likely to be without the most intense field of the grid, so that they will all pass to the grid. Current to the plate will be so prevented.

Supposing that the potential of the grid is such that passage of electrons to the plate is permitted, then for a very small variation of potential of the grid, all the electrons will be attracted to it and the anode current prevented or vice versa. If the variations of the grid potential are caused by an incoming oscillation, the conduction between cathode and plate will accurately follow such oscillations. Hence with a very fine meshed grid, we will be able to obtain a very sensitive valve arrangement, the only objection being that, unless we provide some means to enable the grid to rapidly return to its original potential, passage from cathode to plate will be absolutely prevented.

On the other hand, with a coarse meshed grid, many more electrons are likely to be subjected to the cathode-plate potential gradient and so to pass to the plate, since they have greater possibilities of keeping without the influence of the grid potential gradient, which will be more intense for a given gradient the smaller the distance from the actual metallic grid, since the lines of force are more crowded together per unit volume near the grid than at a distance from it.

With a coarse grid the valve will be less sensitive, but on the other hand there is less possibility of prolonged interruption of the cathode plate circuit, a fact which has practical advantages.

If the grid is moved nearer to the cathode, the lines of force will, in the grid-cathode space, be more concentrated per unit volume than before, so that the grid-cathode field is more intense and any electron has greater possibility of being drawn to the grid, rather than to the plate. The sensitiveness will therefore tend to be greater for reasons given above and vice versa.

Should the grid be given a negative potential, instead of

attracting electrons it will repulse them, prevent the passage of electrons through its interspaces and tend to produce an accumulation of electrons between grid and cathode. Such an accumulation is technically called a "space charge".

Sufficient has been said to describe how instead of a purely thermionic passage of current, we will, in any valve tube, have a more or less complicated passage of current depending firstly upon purely physical causes as electron and molecular collision, and secondly upon the purely mechanical factors of grid mesh, etc.

Since we are dealing with the most minute quantities known to science, it is quite unlikely that methods of manufacture can produce vacua, grids, plates, etc., absolutely the same to such a minute degree. The result is that we cannot absolutely pre-determine the behaviour of a valve before manufacture, and this must be done by actual experiment after manufacture.

In such experimental determinations, our variable factors are, temperature and therefore emission of electrons from the filament, potential slope between cathode (filament) and grid, potential slope between cathode and plate, neglecting gaseous effects due to heat variation.

The most usual course in calibration of a valve is to keep all factors constant, as far as possible, except the potential of the grid which can be varied by a suitable potentiometer and to plot such variations against variations of the current passing between cathode and anode, as measured by the insertion of a suitable milli-ammeter in this circuit.

The curve so obtained is known as the "characteristic" of the valve, and a typical form is:—

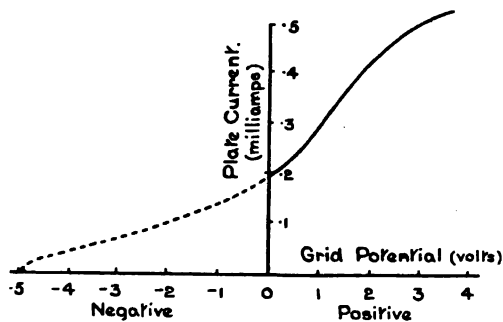


FIG. 73.—Valve characteristic.

This curve shows the plate current when the potential of the grid is both positive and negative.

In the original^{*} Lieben valve, the grid was entirely positive and the steep portion of the grid only was used (see Fig. 70). This suffered from the objection that a comparatively heavy current was always passing in the cathode-plate circuit, which not only had to be best supplied by special very expensive high tension batteries, but also caused rapid disintegration of the electrodes of the very expensive valve tube.

Later valves make use of the more flat negative portion of the curve, which requires a much less heavy plate current and largely overcomes these objections.

To obtain this negative potential on the grid, it is only necessary to apply a suitable potential from a potentiometer, or better with a hard valve, to insert a small condenser (.0003 mfd.) in the grid circuit which is connected on one side to the positive side of the filament battery, so that the other side connected to the grid is of negative sign.

In a well-insulated valve, especially if heavy atmospheric charges were being given to the receiver, there would be a tendency for the grid to accumulate a negative charge, which would grow large enough to entirely reduce the plate current and so put the valve out of action. This is overcome by shunting the condenser with a high resistance (3 megohms) so that the charge gradually leaks away but sufficiently rapid for the grid to acquire its original potential for the next incoming wave train. Such a large resistance is easily obtained by drawing a thin pencil line across a ground glass surface. In a soft valve, ionisation of the gas is usually sufficient to remove such an accumulation of charge on the grid.

The effect of an incoming oscillation can be easily pictured on such a characteristic curve.

For example (Fig. 74) let us suppose the grid is maintained at a negative potential of .5 volts. An incoming oscillation may be represented by drawing new axes of time with this point as the origin and setting the variation of voltage of the grid off as a damped harmonic curve from the grid voltage - .5 beneath the x axis.

Along the other time axis we can then draw corresponding values for the plate current for these values of grid voltage, and we obtain a simple harmonic curve for anode voltage and similarly anode current.

On this negative portion of the curve three cases may arise, which are better represented in Fig. 75 at points A, B, and C.

At a point such as A, the slope of the curve is about 30° but

changing to 45° and an incoming wave train will cause a larger pulse in the plate current for a positive pulse, than for a negative pulse, a result which can easily be shown graphically by the method of new axes just mentioned (Case I.). Hence the mean value of the plate current will be raised above the normal during the period of each wave train. This variation will be repeated in the telephone circuit, and the valve will act as a rectifier or detector, but not to any extent as an amplifier, i.e. it will not cause a magnified current in the plate circuit.

In the second part of the curve B the curve is practically at 45° and an incoming train will give equal positive and negative

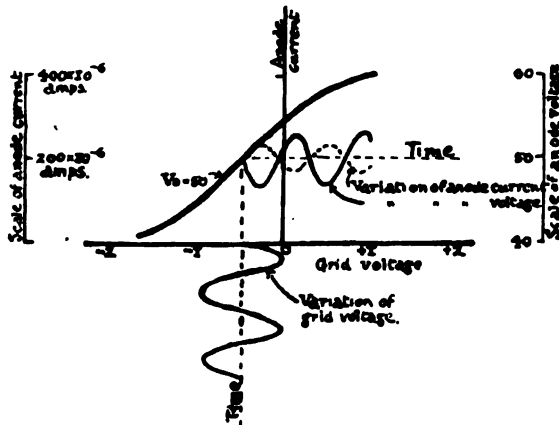


FIG. 74.

pulses (Case II.). No rectification, i.e. variation of the mean telephone current will result, whilst some amplification will occur.

In the third part C of the curve, since the curve is at 45° , but changing to about 30° , we may expect a similar state of affairs as at B, but a positive pulse gives a less telephone variation than a negative pulse (Case III.). Another effect must now, however, be considered, namely, the current which is passing from cathode to grid, which before was non-existent, since the resistance was infinite.

This current is represented in Fig. 75 but not to scale. At the point C the cathode to grid resistance is still very high but not infinite, so that a current will pass when the negative potential is reduced by a positive half cycle but be shut off when the grid potential is made still further negative by a negative

half cycle. At this point, therefore, the valve will not only act as an amplifier but also as a detector.

We thus see that without previous use of a crystal or other rectifier we can use the valve at point A to obtain rectification

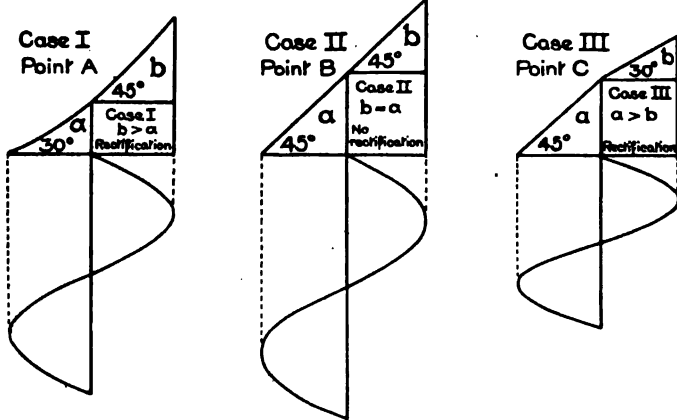
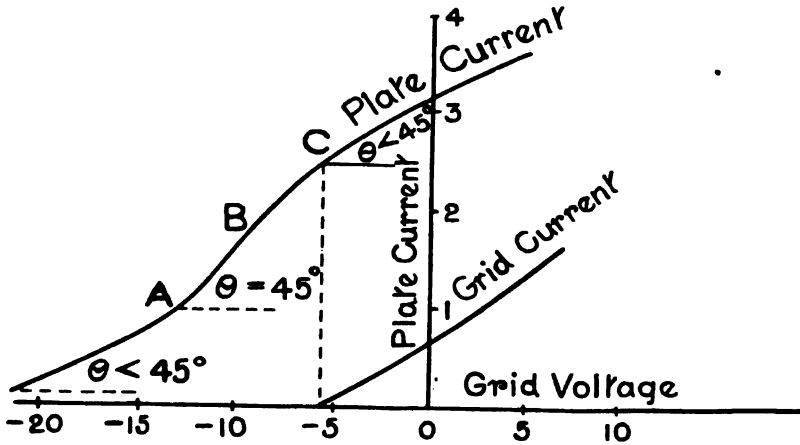


FIG. 75.

but no amplification, at B purely as an amplifier, and at C as a very excellent detector and amplifier. Also at this point 'C, since we do not work at the steep portion of the curve such as Lieben originally used, we shall not have a permanent excessively large plate current with consequent disabilities. Also

when signals are not being received, no cathode grid current passes.

Actual practice has shown that in a multiple valve receiver, without a crystal or other rectifier, it is best to use one valve purely as a detector, that is, working at the point A of the curve and one or more valves as amplifiers of the rectified currents, i.e. working at the point B or C.

It should be noted that since there is always a steady current through the plate circuit, even when signals are not being received, at whatever portion of the curve we use, it is preferable to connect the telephones through a step down transformer, which not only prevents breakdown of their insulation by the high tension of the circuit, but also only permits a current to pass in them when signals are being received. If, therefore, it should happen that they are connected to the receiver so that their magnet's polarity is reversed, they are not subjected to a continuous demagnetising current, but only slightly demagnetised when actual signals are being received.

Such a transformer connection also ensures that should the telephones be earthed by dampness, through the wearer, the alteration of potential is not transmitted to the valve electrodes, which we see needs accurate adjustment for most efficient working.

Having dealt with the variation of the grid potential for the regulation of the valve's action, we may next inquire as to the effect of other means of regulation.

By variation the current passing through the filament by means of a resistance, and therefore the filament's temperature, we can obtain curves of the type:—

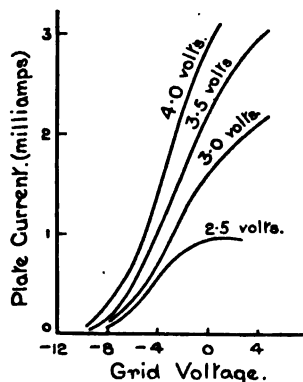


FIG. 76 a.—Effect of filament temperature.

We see the effect is to shift the curve upwards and to make it more steep so that "saturation" does not so rapidly occur. The actual physical effect is to cause the filament to emit more electrons owing to increase of temperature, so that for a given high-tension potential from filament to plate, more electrons are available for the "conveyance" of current, and therefore the saturation value (i.e. when all the electrons pass from filament to plate) is not so easily attained. Whilst this gives greater amplification it also demands a greater plate current and disintegration of the electrodes, a result not to be desired on economical grounds, so that there is a maximum practical current in the filament of any particular valve.

Variation of the high-tension potential across filament and plate gives curves of the type :—

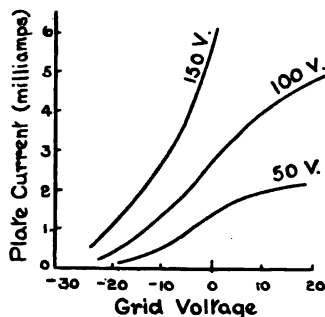


FIG. 76 b.—Effect of increase of high tension.

We see the effect is similar to that of raising the filament current. Physically, for a constant emission of electrons from the filament, a much stronger potential field is provided so that more electrons pass through the grid to the plate, in which circuit therefore there is an increased current, providing the emission from the filament is sufficiently great, otherwise "saturation" is more quickly reached.

In practice it is inadvisable to have too great a potential for reasons similar to those given regarding filament current, furthermore in practice it will be found the valve begins to oscillate, which, for reception of spark signals, may not be desired.

In practice it is more economical to vary the filament current rather than the high-tension potential, since to provide such a potential, usually a large number of specially constructed batteries are used, designed to give a high potential, but only a small

current. To continuously vary this by use of a resistance always carrying and wasting energy would be uneconomical, and such batteries are made to vary step by step over suitable ranges.

This source of high potential is much used by the Marconi Company, and early in the war by the British and French Armies. The present tendency, however, is a reversal to the original practice of the Telefunken Company, in which a specially high-tension D.C. generator was used. This has obvious advantages, the most important being that the potential can be continuously varied by variation of the generator's speed, and that the practical disabilities of high-tension battery maintenance and replacement at high cost are avoided.

Such a generator, however, does not give a steady current but a series of uni-directional pulses of varying potential. Since this would be unsuitable for use with a valve, the difficulty is overcome by inserting a relatively high valued condenser in the high-tension circuit, which serves as a reservoir for the direct current pulses, so that a practically steady potential is applied to the plate circuit. If high-tension batteries are used they should similarly be shunted by a condenser to provide a shunt path for oscillatory currents in the high-tension circuit.

Oscillation of energy through the valve, which forms the basis of the use of valve for transmitters, is similar to the oscillation set up in a spark discharger circuit, namely, the high-tension circuit has inductance, capacity, and resistance, in certain mathematical relations. Unlike the spark discharge circuit, however, the valve has very low resistance, since conduction occurs by the movement of electrons which can be abundantly supplied from the filament by thermionic means. The whole circuit, therefore, can be made of very small resistance, so that oscillations are practically undamped and continuous, any slight damping being overcome at the expense of the high-tension battery.

Retroaction.—As already mentioned a single valve can be used to further strengthen the incoming signals by retroaction (Fig. 71), i.e. by means of a transformer, the primary of which is formed by the plate circuit and the secondary by either the aerial, or grid (secondary of receiver) circuit.

With such an arrangement the incoming signals, already rendered aperiodic and intensified, are caused to further excite the grid of the valve and cumulative effects are given. Theoretically this process could be continued indefinitely, in practice a limit is soon reached, owing to the mechanical construction of the valve

and the current carrying capacities of its electrodes. Also disturbances such as atmospherics may be simultaneously intensified and reading of signals with increased intensification be made more difficult.

The inductance used to "back couple" for such double intensification is known as a "reaction coil". It is of importance that it should be connected up in the right sense or the currents in it will wipe out incoming signals. If this is suspected to occur it can easily be tested by reversal of the reaction coil leads when signals will again be heard. The energy source for such double intensification is the high-tension battery.

In practice variation of the reaction coil will give rise to the following effects:—

1. With loose coupling, there will be little amplification, the valve will act purely as a detector, and musical signals from a distant station will be heard unaltered.

2. As the coupling is increased, amplification as well as detection occurs and the signals increase in strength.

3. With close coupling the signals increase in strength, but the musical note of a Quenched-Spark station becomes a harsh unmusical note. The reason is that the valve is now in an oscillatory state and generating its own oscillations as mentioned above. Two inaudible oscillations are present and these combine with the received oscillations to produce "beats" which have little relation to the 1000 frequency note of pure Quenched-Spark signals. This beat production is known under the more fanciful term of "heterodyne reception".

4. Still closer coupling produces "yowling," i.e. the two oscillations generated by the valve itself (with or without incoming signals) produce beats. Even if the incoming signals are concerned in the beat production, it is difficult to read them owing to the very unpleasant and sustained yowling. Such yowling can be removed by loosening the coupling, and will often be found to be due to a break in the aerial circuit which normally serves to damp the valve oscillations.

In retroaction instead of coupling back the plate circuit, it is possible to couple back the telephone circuit and so intensify the audible currents passing through the telephones.

When using valves another unpleasant effect often experienced is the presence of recurrent "clicks" in the telephones. This is caused by too great a negative potential on the grid of the valve, preventing the passage of electrons through its interspaces, so that the filament-plate circuit is interrupted, until the negative

potential of the grid is reduced by leakage; when the filament-plate circuit is re-established another click is heard. The remedy is to reduce the grid potential if means are present, or otherwise to lower the resistance leak of the grid. Should this be a pencil line resistance, it can easily be reduced by thickening the pencil line, so allowing more rapid leakage. If this is found to have no effect, the coupling of the reaction coil should be loosened, as this may be causing too great a variation of grid potential; should this still have no effect, an intermittent break in the plate circuit should be sought.

The patent situation as regards retroaction is interesting. The first patent embodying retroaction applied for in Great Britain was that of the Telefunken Company due to Meissner. This was shortly followed by application for a similar patent by the Marconi Company and Franklin, the only difference being that magnetic coupling for retroaction was used in the first application and direct coupling in the later. Armstrong in the United States also has a patent for retroaction.

Should the Telefunken-Marconi agreement to exchange patents, now that the war is ended, again become effective, this complication would have little effect, but otherwise the situation offers great legal possibilities.

In such an event, any attempt to monopolise valve wireless work, by virtue of any such patent, would be likely to be very strongly resisted now that so many large electrical concerns, such as the Western Electric Company, General Electric Company, and British Thomson-Houston, are taking up wireless technology.

Moreover, the use of retroaction has become so general throughout the world, particularly in the British and French Armies and in America, that it is unlikely that patents will in future be able to prevent further wireless progress.

Reception of Continuous Wave Signals.—This will be dealt with at further length in Chapter XIII. on Continuous Wave work.

We may briefly state here, that by causing the valve to oscillate, and so to produce audible beats with incoming aerial undamped oscillations, continuous wave signals can be directly received on valve receivers, which therefore have an advantage over crystal receivers which, without modification, are only available for spark signals.

Hard Valves.—As already mentioned, modern valves all tend towards being of the "hard type" in which the transfer of electrical energy is nearly purely thermionic, and gaseous ionisa-

tion effects have little or no part. This promotes more steady action, and longer life of the valve since the cathode is not rapidly disintegrated.

The means of obtaining the very high vacua used have been worked out within the past few years, largely by Meissner in Germany, and Langmuir in the U.S.A.

To show the difficulties of obtaining very high vacua, the author believes there is no better way than to quote a portion of British Patent Specification No. 15,788 of 1914 of the General Electrical Company of Schenectady, which is founded on Langmuir's work, and is a document not only of interest as a patent but of scientific interest.

"In devices made in accordance with this invention gas ionisation is either entirely absent or is negligible, and a discharge takes place which is distinct in its characteristics from the described discharge taking place in an ionised gas.

"The cathode is not heated by the discharge itself. Blue glow and in fact all visible indications of a discharge are absent. Glass fluorescence is absent in a device operating with a pure electron discharge. The discharge current passing through a given space with the cathode at a sufficiently high temperature varies directly with the $3/2$ power of the impressed voltages. The discharge is independent of the vacuum, providing the pressure is below the minimum at which gas ionisation by collision will take place. As distinguished from discharges in the presence of positive ionisation, the pure electron discharge is characterised by regularity and reproducibility with given conditions.

"Devices made in accordance with this invention may be used for various technical purposes, such as relaying and detecting currents, producing oscillations and rectifying alternating currents with currents thousands of times greater than the minute currents at which the devices above referred to were operable.

"The gas occluded in metals and driven out by the electrons impinging thereon appears to be especially liable to ionisation, as it may be observed that gas eliminated from the anode even when below the pressure permissible for residual gas produces the effects accompanying gas ionisation. In fact, gas thus eliminated from the anode may not even produce a difference in the reading of a McLeod vacuum gauge and yet produce ionisation effects.

"It is found that deleterious gases may be removed by electron bombardment even at a low temperature, which is advantageous as the device may not be adapted to receive a high energy input,

or current of sufficiently high voltage may not be available. For the evacuation of the device the glass walls of the tube are carefully heated to as high a temperature as the glass will stand without softening and in general the most approved methods of incandescent lamp exhaust are used. The evacuation of the tube, preferably while still heated, is carried out by the aid of a suitable evacuating means, for example, a Gaede molecular pump, which removes vapours as well as gases. Chemical evacuating means such as electrically vaporised calcium or magnesium may also be used. Either before or during the evacuation the anodes may be heated, especially when the anodes are to be run at an elevated temperature during the normal operation of the device. In this case the temperature is preferably carried to brilliant incandescence by passing an electrical current. The heating may take place in a suitable vacuum furnace, the temperature preferably being raised to 2500° C. or even higher. However, heat alone will not remove all the gas liberated by the electron discharge, but this gas is driven out even at ordinary temperatures by the discharge itself. The discharge appears to affect especially the surface of the metal. Heating is a valuable aid in bringing gases from the interior of the metal body into the sphere of action of the discharge but may be omitted when the devices are not heated during normal operation.

“The bombardment is carried out when the evacuation has proceeded to a high degree by applying a potential between the cathode and the anode, the value of which depends upon the character of the device. Care should be taken to use a voltage below that at which a blue glow appears as this indicates harmful gas ionisation, and, as already pointed out, sputtering and disintegration of the cathode accompanies or closely follows the blue glow phenomenon. The pump should be constantly operated to remove the gas. After the removal of the gas thus driven out the voltage impressed between the cathode and the anode, or anodes, as the case may be, is increased, thereby driving out more gas. This process is continued step by step with a progressively higher voltage, the final voltage depending upon the character of the apparatus. In most cases the final voltage should be materially higher than the voltage at which the device is to be used in actual service. However, in the case of devices that use exceedingly high voltages, such as 50,000 volts or even higher, substantially all the gas may be removed from the anode without resorting to voltages higher than the normal operating

voltage. In the case of a plate-shaped anode which cannot be readily heated by passage of current, the discharge voltage may be chosen great enough to convey sufficient energy to the anode to raise its temperature to redness or even higher, when the device is to be used with a discharge current adapted to heat the anodes. In the case of a device in which the anode normally operates at low temperature, bombardment without heating may suffice. After the metal has been freed from occluded gas, re-absorption of gas will not take place even though it is exposed to the air or other gases. For example, anodes thus treated may be removed to other apparatus which then may be evacuated without further electron bombardment of the anode or anodes.

"The evacuation of the device should be preferably carried to a pressure as low as a few hundredths of a micron, or even lower, but no definite limits can be assigned. The residual gas pressure should be below the value at which ionisation by collision will take place at the given working voltage and current, with its accompanying phenomena of blue glow; disintegration of the cathode and so forth. When the cathode and anode are located in close proximity and the discharge confined to the region between the same, the permissible pressure is higher than when the cathode and anode are at some distance. It is also true that when the anode has been carefully freed from gas, residual free gas even if present in a sufficient amount to cause some gas ionisation when the apparatus is first started, does little harm, as it is quickly removed by the gas clean-up effect when the device is operated.

"Electron discharge apparatus thus provided with a gas-free pre-treated anode or anodes may be constructed to handle currents at a very high voltage by proper mechanical design of the parts subjected to static strains, suitable proportioning of the parts and so forth.

"The tube is exhausted to the highest possible degree of vacuum, the gas being driven out of the walls of the tube as well as out of all of the metal electrodes. Under those conditions the current flow in the tube between the incandescent cathode and the plate or anode is due to a pure electron discharge from the heated cathode and is not dependent upon the presence of residual gas as a conducting medium."

Effect of a Trace of Gas in a Hard Valve.—W. C. White of the American G.E.C. discovered that if into a hard valve a trace of gas was intentionally permitted to enter, its sensitiveness

as a detector could be much increased. If a characteristic for such a valve is taken (Fig. 77) the curve exhibits a kink at which either an increase or decrease of the grid potential causes a decrease in the plate circuit. Should the valve, used as a detector, be adjusted to the point at which this kink occurs, reception of signals is more sensitive.

It should be particularly noted that the quantity of gas needed to obtain this effect is very much smaller than that present in a soft valve of the Audion, Lieben, or Round type, as will be evident from the further extract from the patent specification already mentioned.

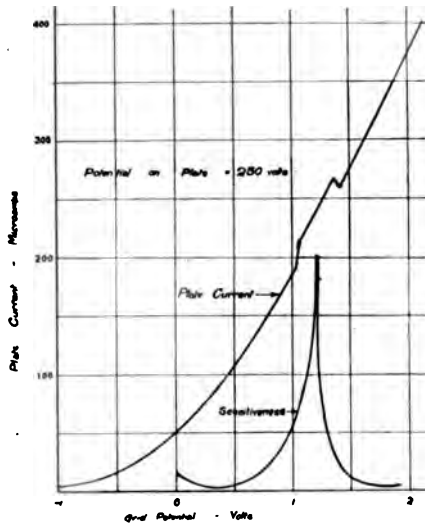


FIG. 77.

“ If, however, a certain amount of residual gas be present in the tube then the operation of the device becomes quite different. Such a construction and mode of operation is that characteristic of the ‘ Audion ’. In the ‘ Audion,’ if very low voltage be used in the local or plate circuit, the device is relatively very insensitive, or in other words the change of current in the local circuit is very small for a given change of potential on the grid. The device becomes more sensitive as the voltage in the local circuit is increased. There is a limit, however, to the voltage which may be used in the local circuit because as the voltage is increased ionisation of the gas in the tube increases, a blue glow appears followed by deterioration of the electrodes, disengagement of

more gas therefrom and finally destruction of the operative qualities of the tube. The voltage impressed on the local circuit is therefore made as high as possible consistent with the avoidance of these limited conditions. In the 'Audion' as thus constituted, a decrease of potential on the grid causes a decrease of current in the local circuit, while increase of potential on the grid causes an increase of current in the local circuit, but the decrease of current is of a magnitude very much greater than the increase of current caused by an increase of potential on the grid. The result is that when high-frequency oscillations are impressed upon the grid their presence is made known by a decrease of current in the local or plate circuit, which decrease is detected by the telephone or other indicator placed in the local circuit.

"It has been found that by maintaining within the evacuated container a certain definite pressure of gas, which in amount is very much less than that which is necessary to make the 'Audion' operative, and not much higher than would be tolerated in a device such as described above, very remarkable results are secured in the relations which then exist between the current in the plate circuit and the changes of potential on the grid. With this definite pressure of gas or vapour in the device it is found that the variation of current in the plate circuit with variation of potential on the grid follows the law of a pure electron discharge tube such as that described above, except within a small range of voltage in the grid circuit. Within this small range there appears to be a condition of instability such that when high-frequency oscillations are impressed upon the grid there always follows a sudden decrease of current in the local circuit. The explanation of this phenomenon is decidedly obscure but the existence of the phenomenon is very real. Within the range of voltage indicated, the application of high-frequency oscillations or of continuous high-frequency waves causes the current in the local circuit to decrease so suddenly that a very distinct signal is produced in the telephone receiver or other indicating device in the local circuit. The sharpness of the signal thus produced is such that the device is not only, extremely sensitive to receive high-frequency impulses but because of the sharpness of the signals the effect of 'static' is not nearly so serious as in other detecting devices at present in use.

"While this form of detector is dependent upon the presence of a small but definite gas pressure in the space including the electrodes, its operation is not accompanied by blue glow or any

other well-recognised evidences of positive gas ionisation. The amount of gas or vapour present is perhaps not more than one-tenth of that which characterises the 'Audion'.

"The sensitiveness of this device varies with the potential impressed upon the grid and becomes a maximum at a certain definite potential. To secure this maximum sensitiveness a definite potential which varies according to the particular device is impressed upon the grid circuit. As this potential is changed by the high-frequency oscillations the current in the plate circuit is suddenly decreased, thereby producing the desired signal.

"In producing and maintaining the desired gas pressure in this device it is not sufficient to leave in the tube a certain amount of residual gas during exhaustion since this gas does not remain constant in amount but generally will decrease upon operation of the device by the well-known clean-up action, though in some cases the amount of gas present increases rather than decreases, due to other causes. To secure the necessary definite gas or vapour pressure in the tube, a substance with the desired vapour pressure is provided and placed in the tube. Among other things it has been found that amalgam is suitable for the purpose. Mercury alone appears to be unsuitable, as it has too high a vapour pressure at ordinary temperatures though by lowering the temperature of the mercury the desired vapour pressure may be obtained.

"For the evacuation of the device the glass walls of the tube are heated so as to free them from moisture and both the anode and the cathode are heated by passage of current so as to drive out the gases. When an amalgam is to be used as the source of vapour, the metal to be amalgamated, for example silver, preferably is placed in the envelope before evacuation. The mercury is preferably placed in a side chamber which is kept cool during the preliminary bake-out. The evacuation of the tube is carried out by the most approved methods of incandescent lamp exhaust, and the last traces of gas are removed by either a Gaede molecular pump or by some chemical evacuating means. The last traces of ionisable gases are also removed from the electrodes by heating them to incandescence and preferably at the same time operating the grid as the anode for an electron discharge, the impressed voltage being increased step by step as the gas is removed. After the parts of the device and the silver, or other metal to be amalgamated, has been freed from gas, mercury vapour is permitted to diffuse into the envelope; for example, clean mercury may be kept at a relatively low tempera-

ture in a side chamber during the exhaust. When the exhaust is completed the mercury may be permitted to reach room temperature, or even higher temperatures, thus diffusing into the main envelope to form silver amalgam. At room temperature one or two days are required for the amalgamation. All excess unalloyed mercury must be removed from the tube. This may conveniently be done by warming the bulb slightly and surrounding the mercury side tube in a freezing mixture, or in liquid air. The mercury side container may then be sealed off. When evacuation of the envelope has been carried to a pressure low enough to enable the pure electron discharge to take place and ionisable gas has been removed from the anode to a sufficient extent to prevent the blue-glow phenomenon which is an indication of positive gas ionisation, the envelope is sealed off. A device thus prepared will operate at ordinary room temperature with a substantially pure electron discharge between anode and cathode without positive ionisation, even when the impressed voltage is as high as 300 to 400 volts, or even higher. However, when the voltage on the grid circuit is within a certain range an irregularity is observed in the electron discharge current, as already described."

Typical Valves.—At the present day the number of valves is becoming extremely numerous. With very few exceptions the greatest differences are those of design only, for example, the Round valve, except in size and shape of electrodes, does not differ physically from its progenitor the Lieben valve. A very convenient précis of valve patents is given in the "Marconi Year Books" for 1917, 1918, and 1919.

We shall therefore confine ourselves to the Lieben valve, which is a typical soft valve, and of interest, since it was the first valve intensifier to be used for wireless purposes, and also the original valve transmitter.

As an example of a hard valve, Langmuir's Pliotron will be described, which is a valve capable of carrying very heavy currents, so that it is, as well as being an amplifier, a typical example of a valve transmitter.

Hull's "negative resistance tube" has new physical features, and Brown's valve is of interest as a modern two-electrode valve.

Those requiring descriptions of further valves are referred to Eccles, and to the numerous valve patent specifications of the past few years.

The Lieben Valve.—The form of relay tube adopted is

shown in Fig. 78. The anode A consists of a spiral of 2 mm. aluminium wire. The cathode or filament is a platinum strip about 1 metre in length, 1 mm. width, and 0.02 mm. thickness, and is covered with a thin layer of calcium or barium oxide, and there is a second cathode H formed by a grid of aluminium having a number of apertures $3\frac{1}{2}$ mm. in diameter. The electrical connections are made by means of non-interchangeable bayonet plugs at the base of the lamp.

The gas may have its conductivity increased by the presence of ionised vapours, such as that of mercury. This mitigates the ageing of the tube due to occlusion of the residual gas, the mercury vapour taking over the work of ionisation. In practice, an amalgam of mercury is used, as the vapour pressure of mercury rises rapidly about 20° C., and gives rise to the too easy passage of current, which is injurious to the electrodes.

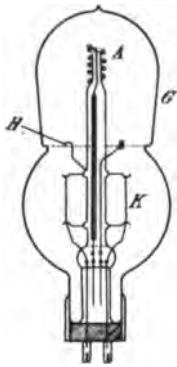


FIG. 78.—Diagram of Lieben valve.

Fig. 79 *a* shows the complete apparatus, and Fig. 79 *b* the connections for the intensification of signals from a spark transmitter. By means of the battery B the cathode is maintained at red heat. For this purpose only accumulators are permissible, since the glow of the filament used must not vary to any great extent.

The voltage between the anode E, and cathode K₂, of the tube is usually 220 volts, and may be supplied by either accumulators or a D.C. generator, but in the latter case a choke coil must be inserted to remove the effect due to the commutator of the generator, which, as each segment meets and passes a brush, causes a clicking sound to be heard in the telephone. By means of a resistance the voltage applied from the generator is adjusted so that there is a very small flow of current between the anode E and the cathode K₂. If, now, signals from the aperiodic circuit K of the wireless receiver are led through the transformer C to the grid anode K₁ and filament K₂, a sufficiently great disturbance of the potential gradient is produced by the wireless impulse to allow the passage of a fairly heavy current from the machine between E and K₂.

This passage of current will continue so long as the wireless signals persist, and then immediately stop, so that in the circuit feeding across EK₂, there will be a flow of current following that



FIG. 79 a.—Lieben valves for intensification of spark signals.

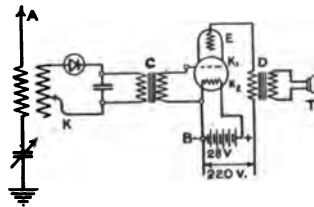


FIG. 79 b.—Connections of Lieben valve (spark signals).
[To face p. 188.]

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of the wireless signals in the aperiodic circuit K, and as the current in the machine circuit is much heavier, a telephone placed in this circuit will produce greatly intensified signals. In practice, in order to avoid high-tension shock, the telephone T is inductively coupled by the transformer D, the transformer C similarly protecting the windings of the receiver from being injured.

If further intensification is required, the current from the secondary of the transformer D may be applied to the grid and cathode of a second relay, when the signals will be again magnified. With four relays in such "cascade" connection, magnifications as high as 20,000 have been obtained.

The great advantage of this relay is that since it does not essentially depend on magnetic induction it possesses little electric inertia and is able to accurately follow the oscillations to be intensified, and is therefore a means of intensifying weak telephonic currents without mutilation of speech.

The application is by no means restricted to wireless work. The high-frequency vibrations employed for this purpose are capable of intensification to 75-100 fold with one standard relay tube. Vibrations of low frequency as used in wire telephony may be intensified to 25-50 fold, and the relay may also be applied to vibrations of mixed frequency used in wire telegraphy.

The actual appearance of the apparatus is shown in Fig. 79 *a*. The terminals at the front on the left-hand side go to the transformer, which couples the apparatus to the wireless receiver. The receiving telephone is joined to the centre pair of terminals leading to the transformer D for single magnification with one valve, or the right-hand pair for double magnification with both valves.

The regulation of the high-tension current is brought about by a resistance controlled by the knob in front of each valve. Switches in the filament circuit are on the apparatus to put the valves in or out of use, as required.

The apparatus seen to the left is the terminal board for connection to the 32- and 220-volt circuits respectively, which also contains (Fig. 80) fuses M.B.B., choke coil C, to stop interference due to the commutator of the high-voltage generator, and a charging resistance R, which is put in circuit by switch S, when the apparatus is out of use, and the filament battery is being charged.

Reception and Intensification of Continuous Waves with the Lieben Valve.—The apparatus already described provides a simple and reliable means for the reception of continuous wave

signals. The difficulty of direct reception of continuous wave is due to the fact that the receiving telephone responds, not to each electrical oscillation, but only to the wave *trains*, at least one of which is set up every time a spark is formed at the transmitter, the regular sequence of the sparks producing the "note" of the signal heard.

With continuous wave stations only one continuous wave train is produced during the period that the sending key is depressed, and with a crystal detector the telephone receiver does not respond sufficiently rapid, and some mechanical device, such as a "tikker," is necessary to break up the single continuous wave train.

It is found with the Lieben relay that if the valve is electrically "soft"—i.e. the gas in it is rarefied to an extent

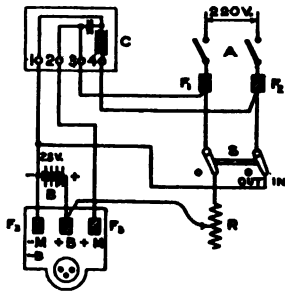


FIG. 80.—Connections of valve apparatus to source of current.

which gives maximum electrical conduction (further rarefaction increasing and not decreasing resistance to the passage of current)—it is possible, by means of a fine regulating resistance in the filament circuit, to produce such a fine balance of potential in the valve that the slightest alteration will cause the high-tension circuit to oscillate, in very much the same manner as an ordinary Hertzian oscillator does when a spark passes across the electrodes.

Under these circumstances, once a passage of current commences the resistance of the gas becomes exceedingly small, and the high-tension circuit having very small damping, the oscillations have such a small decrement that practically continuous oscillations are produced, one wave train not dying away before another occurs.

If now this oscillatory state is obtained in the high-tension circuit, and continuous wireless oscillations from the receiver be superimposed upon them, since they differ in phase the two wave trains will produce "beats" which are audible in the telephone, and so permit continuous wave stations to be received by this method.

The arrangement for continuous wave reception is shown in Fig. 81 *a* where the fine adjustment resistance may be seen joined to an intermediate piece between the valve and its stand.

The connections for continuous wave reception are shown in Fig. 81 *b*. A is the normal receiver, and K an oscillatory circuit,

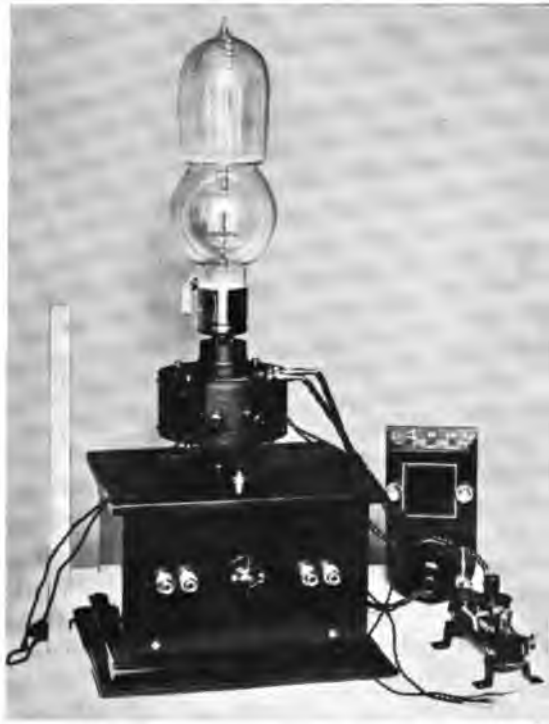


FIG. 81 a.—Lieben valve for continuous wave intensification.

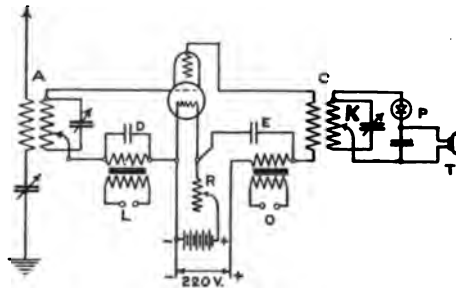


FIG. 81 b.—Connections for continuous wave intensification.
[To face p. 190.]

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in shunt to an aperiodic circuit containing a detector P and a telephone T.

It is possible to both rectify and intensify signals with the same valve. For this purpose it is necessary to connect the telephone sockets L, the telephones then being placed in sockets O, which permits the continuous signals, after rectification, to be led back to the valve, which further intensifies them, as much as 100-fold.

A little study will show that transformer between L and blocking condenser D is then the same as the transformer C in Fig. 79 *b*, while the transformer between blocking condenser E and sockets O is the same as the transformer D in this figure.

By means of these valves it is also possible to *transmit* continuous wave signals, the method being, briefly, to cause the high-tension circuit (containing extra inductance and capacity) to oscillate as already described, and so to excite an aerial circuit either by magnetic or direct coupling (see Chapter XIII.).

In using the apparatus it is necessary to heat gradually the filament electrode some little time before signals are to be received, but it must not be heated above redness. When the voltage is too high in the anode circuit it gives rise to ticking noises. This must then be regulated by the knob upon the top of the base of the apparatus.

The tube gives the best result when the cathode dark space beneath the auxiliary electrode is from 1 to 2 cm. high. If the lower spherical part of the tube is filled with luminosity and the upper part is dark, the anode voltage is low or the cathode is not being sufficiently heated. Unnecessary passage of current between electrodes is to be avoided, as this destroys them.

It should be remarked that the Lieben valve is practically unknown in England, so that various published accounts of its actual relative working, as compared to other later soft valves, should be received with caution.

As far as the author is aware there are only two examples in England.

One the author had the opportunity of dealing with was loaned in 1914 by the Telefunken Company to a very well-known member of Parliament for private research.

The other, the author has been informed is at Marconi House, and was doubtless sent by the Telefunken Company to the Marconi Company to enable Round and Franklin of the latter company to collaborate in Meissner's early transmission

experiments in 1913, as he mentions in the "Jahr. der drahtlose Telegraphie," Vol. XV.

Later Telefunken Valves.—Whilst transmission was first carried out by Meissner on the Lieben valve, he found, owing to its softness, the filament was so rapidly disintegrated that its life was extremely short. He therefore sought to produce a valve dependent upon purely thermionic phenomenon. An account of his experiments to obtain extremely high evacuation are to be found in the article just mentioned. In effect they are the same means adopted independently, but simultaneously, by Langmuir and already detailed in this chapter.

The resulting form of valve is shown in Fig. 72 (9). It consists of a glass vessel which is of about the same size as the English Round valve, which is, however, a soft valve. It offers, however, very great advantages as to mechanical strength in its design. Instead of the filament being liable to drop and touch the grid, it is stayed off and kept taut by a spring SS.

The filament consists of two wires and are surrounded by a grid formed by wrapping a wire round two insulating uprights. Connection from the grid is made to a pedestal through which the filament leads also pass.

The anode is double and consists of plates on two pairs of uprights. Connection is made to a terminal mounted upon the top of the valve.

All the connections are therefore rigid and good contact can be made. A similar transmitting valve is shown in Fig. 72 *a* (4). This type of valve although suitable for both transmission and reception is largely used for Telefunken continuous wave transmitters, which have been very largely adopted in Germany, and even so far away as the mercantile marine of South America.

Other smaller and more simple valves are usually used for reception. These offer no great interesting differences, and those requiring further details are referred to Stanley's book. An example is seen in Fig. 72 *a* (3).

One such type follows the French valve very closely, and according to Stanley was produced after the capture of French valves in military operations.

The Plotron (Langmuir).—This is a hard valve, and the transmitting type has already been illustrated in Fig. 72 *a* (2) and Fig. 82 *b*.

For reception the plates are usually replaced by wires as shown in Fig. 82 *a*.

"As shown in Fig. 82 *a*, the various parts of the apparatus

may be mounted in a tube, or globe, upon a pedestal, similar to the mount used in incandescent lamps. The cathode is centrally located and may consist of a short straight filament C not

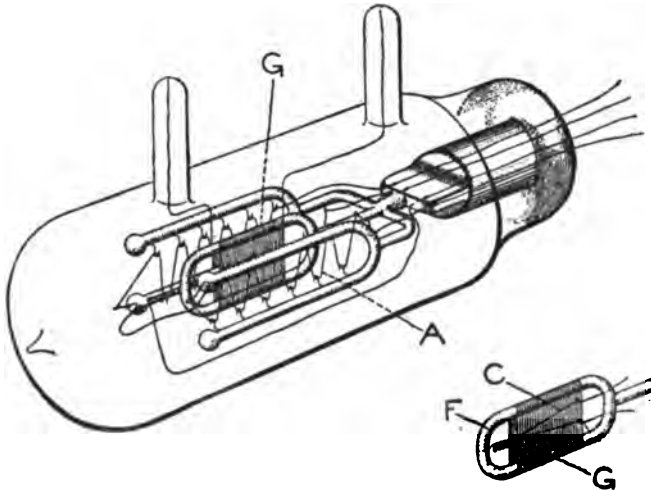


FIG. 82 a.—Langmuir Pliotron for reception.

seen in Fig. 82 a but shown plainly in the smaller figure. The filament consists of one or more V-shaped conductors. Either form may be used, the particular form of filament being ordinarily

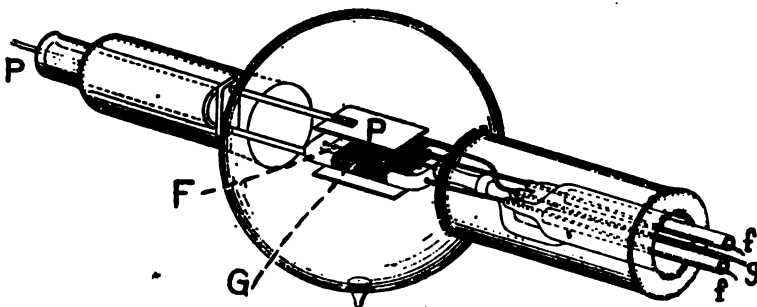


FIG. 82 b.—Langmuir Pliotron for transmission.

determined by convenience of construction. Preferably the filament conductor is held taut by a spring to avoid contact of the filament with the grid, by sagging, when the metal is expanded at a high temperature. The filament is mounted between two oppositely disposed supports, in this case con-

stituting a closed loop, which may consist of insulating material, such as glass or quartz, but in some cases may to advantage consist of metal. Upon this framework is wound a wire *G*, ordinarily called a grid. The turns of the wire are closely adjacent to each other, and are also very closely adjacent to, but are out of contact with, the incandescent filament. By means of this grid, potential may be applied to exert a static control upon the movements of the electrons. A negative potential applied on the grid reduces the flow of current from cathode to anode in proportion to the degree of negative charge. A positive grid potential assists and directs the flow of current from filament to anode in proportion to the degree of its charge.

"The supporting framework for the filament and grid is attached to a rod, mounted upon the stem of the tube. Adjacent to the filament and grid is the anode which in the present case has been indicated as consisting of a wire strung in a zig-zag manner over hooks upon forked-shaped supports, but it is not necessary that it should assume this particular form. Both anode and grid preferably consist of tungsten, but other refractory metals may be used. By making the anode a continuous conductor it can be conveniently heated by the passage of current during evacuation of the device and for this purpose is attached to leading-in conductors, although but one terminal is ordinarily necessary.

"As stated above in some cases it is desirable to use one or more V-shaped incandescing conductors for the filament and to attach to the bights springs to prevent contact of the conductor with the grid by sagging when the metal is expanded at high temperature. A plurality of loops are used in order to increase the amount of cathode surface. The filaments are connected in parallel by means of conductors.

"The filament has been shown as being mounted in a frame, consisting of ferrochrome, tungsten, or other suitable metal upon which the wire constituting the grid is wound. As the grid wire is thus wound upon a conductive frame its turns are in parallel and electrical contact may be made directly to the frame. The leading-in conductors for the cathode are insulated from the frame by glass supports as indicated."

The Negative Resistance Tube.—This valve depends on special phenomena, whereby should an electron strike a conductor at a certain critical velocity, it may liberate an increased number of secondary electrons, an effect first noticed by J. J. Thomson, who gave the name "delta rays" to the secondary electrons.

This effect has been utilised by Hull of the American General Electric Company to construct a valve which may be used to give a large intensification of wireless signals, or to generate continuous waves.

The connections of this type of valve, Fig. 72 *a* (13) and Fig. 83, known as the "dynatron," differ from the preceding types in that the secondary of the receiver instead of being connected across grid and filament is connected across grid and

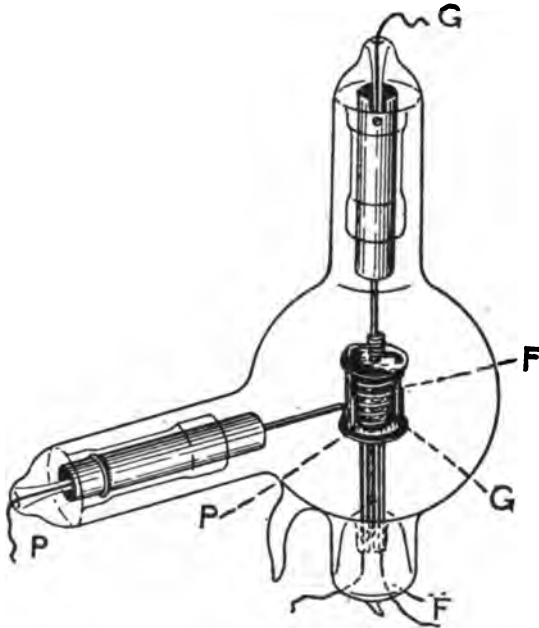


FIG. 83.—"Dynatron" or negative resistance tube.

plate, whilst the high-tension circuit is across filament and grid, i.e. the connections are reversed.

Since it is found that at the critical electron velocities mentioned above an increase of potential gives decrease of current, unlike an ordinary ohmic resistance, the device is known as a "negative resistance" tube.

If in such a valve the cathode is connected to earth and heated to incandescence and a positive potential is impressed upon the anode, there will be a flow of electrons from cathode to anode. If the plate is also at earth potential, no electrons will be received thereby, because it is at the same potential as the

cathode. If, however, a small positive potential is applied to the plate, a portion of the electrons which pass through the grid anode will strike it and it will receive a charge of negative electricity. The velocity with which these electrons will strike the plate will depend upon the potential difference between it and the cathode. If this potential is increased, the velocity will increase until the electrons striking the plate are able, by their impact, to liberate secondary electrons. These secondary electrons leaving the plate will be attracted to the more positive anode. As the potential is increased, a point will finally be reached at which the number of secondary electrons leaving the plate is just equal to the number of primary electrons that strike it, that is, each electron that strikes liberates on the average one secondary electron. No

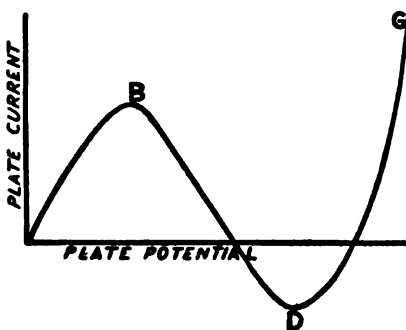


FIG. 84.

current will then be received by the plate. If the potential of the plate is further increased, the number of secondary electrons given off becomes greater than the number of primary electrons received, and as the result the plate loses electrons, thereby supplying current to the anode instead of receiving current.

These characteristics can best be understood by reference to the curve shown in Fig. 84, in which the ordinates represent the electron current flowing to or away from the plate and the abscissæ represent the potential of the plate. The part from the origin to B represents the increasing electron current reaching the plate as the potential is increased. When the potential of the plate increases beyond that corresponding to the point B, the rate of increase in primary electrons received exceeds the rate of increase in secondary electrons and the current begins to decrease. When the potential of the plate again reaches the x axis, it loses as many electrons as it receives, and the current becomes zero. From the x axis to D the number of secondary electrons given off continues to increase and the electron current from the plate to the anode increases. The point D is finally reached, however, at which the potential of the plate so closely approaches that of the anode that the

number of secondary electrons lost by the plate begins to decrease because of the fact that the difference of potential between anode and plate is not great enough to attract as many electrons to the anode as before. This continues until the x axis is again reached, where the number of secondary electrons which leave the plate and do not return is equal to the number of primary electrons which strike it, and the current again becomes zero. From this point the electron current received by the plate increases with increase in its potential until the point G is reached. The part BD of the current curve is approximately straight and may be represented by the equation $I = I_0 - \frac{E}{R}$ where E is the potential of the plate I_0 and R are constants depending upon the characteristics of the particular device and I is the electron current flowing to or away from the plate as $I_0 - \frac{E}{R}$ is positive or negative. R corresponds to the resistance of an ordinary circuit except that in this case it is a negative resistance. Thus it will be seen that there is a certain range through which the device may be operated in which the current received by the plate will decrease as the potential applied thereto increases. The term negative resistance is used to designate a device having negative resistance characteristics.

It is not at all essential in the device that the portion BD of the current curve should extend below the axis, and in case it does extend below the axis, as in the example given, it is immaterial from which portion of the line BD the normal electron current arises.

If in the above notation e_1 is the drop of voltage due to the resistance R of the receiver circuit, e_2 is the drop of potential in the valve of resistance $-r$, we may write—

$$e_1 = IR$$

$$e_2 = -Ir - (-I_0r) = r(I_0 - I).$$

Let V = total voltage of the secondary of the receiver then—

$$V = e_1 + e_2$$

$$= RI + r(I_0 - I)$$

$$= (R - r)I + rI_0$$

$$= (R - r)\frac{E}{R} + rI_0$$

whence

$$\frac{dE}{dV} = \frac{R}{R - r}$$

By making $R - r$ very small this ratio can be made very large, so that a small impressed voltage dV from the aerial can produce a greatly amplified pulse dE , in the secondary circuit. Similarly for current amplification when the valve is in shunt across the receiver circuit

$$I = i + i_2 = V \left(\frac{1}{R} - \frac{1}{r} \right)$$

$$\therefore \frac{i_2}{I} = \frac{r}{R - r},$$

which, if R nearly equals r , is very large.

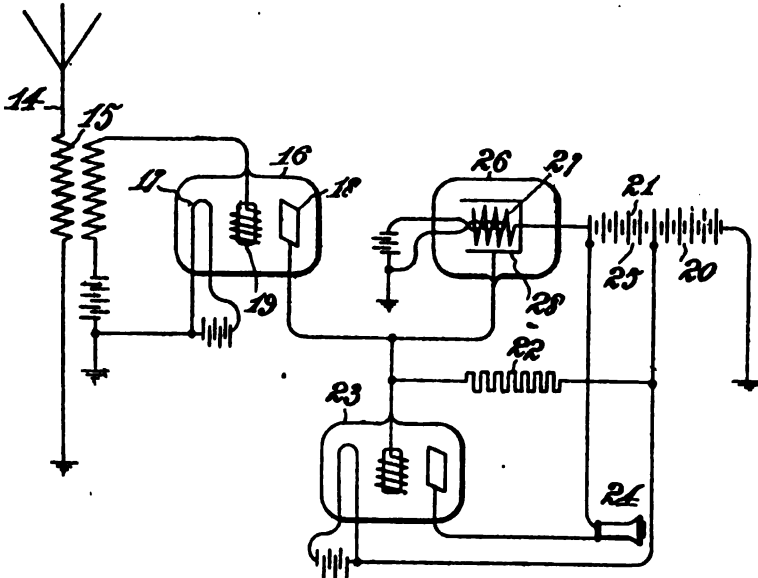


FIG. 85.—Connections of negative resistance tube.

The actual connections for reception are shown in Fig. 85. The receiving system here shown comprises an antenna, 14, which is coupled by means of transformer, 15, to the grid circuit of an Audion amplifier, 16. This device comprises a filament cathode, 17, a co-operating anode, 18, and an interposed discharge controlling grid, 19, enclosed in a highly evacuated envelope. The plate circuit of this amplifier is supplied with current by the portion, 20, of battery, 21, and includes a resistance, 22, which is connected in the grid circuit of a second Audion, 23, similar in structure to the first. The plate circuit of this amplifier which

includes the telephone receiver, 24, is supplied by the portion, 25, of battery, 21. Negative resistance device, 26, has its anode, 27, supplied with a constant positive potential by battery, 21, and its third electrode, 28, connected in series with resistance, 22, and battery, 20.

When signals are received by the antenna, 14, the potential of grid, 19, is varied and the current flowing in the plate circuit of amplifier, 16, varies accordingly. If for the moment the effect of the negative resistance is neglected these changes in current will produce corresponding potential variations across the terminals of resistance, 22, and thus vary the potential of the grid of amplifier, 23, and cause a corresponding variation in the current through the telephone receiver, 24. The current flowing in the plate circuit of amplifier, 16, depends upon the potential of grid, 19, and upon the difference of potential between the electrodes. As the current through resistance, 22, increases the drop of potential therethrough increases and the difference of potential between the electrodes of amplifier, 16, decreases. Hence the current flowing through amplifier, 16, will not increase to the value which it would reach if this potential remained constant. This effect, however, is compensated for by the negative resistance which acts in this respect in a manner directly opposite to that of the amplifier. As the potential difference between the electrodes of amplifier, 16, decreases the same decrease occurs in the potential difference between the cathode and plate of the negative resistance and the current therethrough increases. The drop through the resistance, 22, is due to the total current flowing therein or the sum of the two currents, and as these both increase at the same time the increase in the total current will be much greater than would be the case if the negative resistance was not employed. In other words, the amplification may be made much greater than would be possible without the negative resistance. In practice it will be found that the best results are obtained when the negative resistance is given such a value as to compensate as closely as possible for the resistance both of the amplifier, 16, and the resistance, 22. When the potential of grid, 19, becomes more negative and the current in the plate circuit of the amplifier decreases, the action is just the reverse of that above described.

The actual form of tube adopted has been shown in Fig. 83, the filament is a spiral of tungsten, the grid a larger and stouter spiral, and the plate a cylinder of metal. The plate is fairly close to the anode, and the vacuum is high.

The Brown Valve.—S. G. Brown in British Patent 104,566 describes a novel type of relay in which only two electrodes are present, a plate and a filament, but unlike the Fleming valve it employs a high vacuum.

The novelty consists in the incoming signals passing to the heated filament and thereby varying its thermionic emission, so that corresponding variations occur at the plate and filament circuit causing magnified charges in a telephone coupled to this circuit.

Retroaction between filament and filament-plate circuits is provided for by the coil HH (Fig. 86).

Valve Receivers.—Whilst the variations of valve form are numerous, the methods of connection are still more so.

These modifications may have original crystal detection and subsequent intensification by one of more valves in series, or intensification by retroaction.

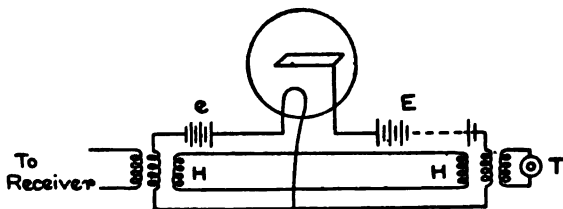


FIG. 86.

It is usually most profitable, if a crystal detector is not used, to have one valve as a detector and one or more as amplifiers. Whilst a good crystal is more sensitive as a detector than a valve, on the other hand troublesome adjustment of poor crystals is avoided by its use.

As an example of a present-day instrument one may take an example now used in the British Army Wireless Signals (R.E.). This valve receiver described by Turner in the "Journal of the Institution of Electrical Engineers," Vol. 75, and illustrated in Figs. 87 *a* and *b*, offers novel features in so far that incoming signals are caused to have a "trigger-like" action upon a thermionic valve E and to set it into the oscillatory state. This oscillation state involves a relatively large amount of energy drawn from the valve batteries, which follows the duration of incoming signals. The increased oscillatory energy is then caused to work an electro-magnetic relay B, the tongue of which gives audible signals as on an ordinary line sounder instrument.

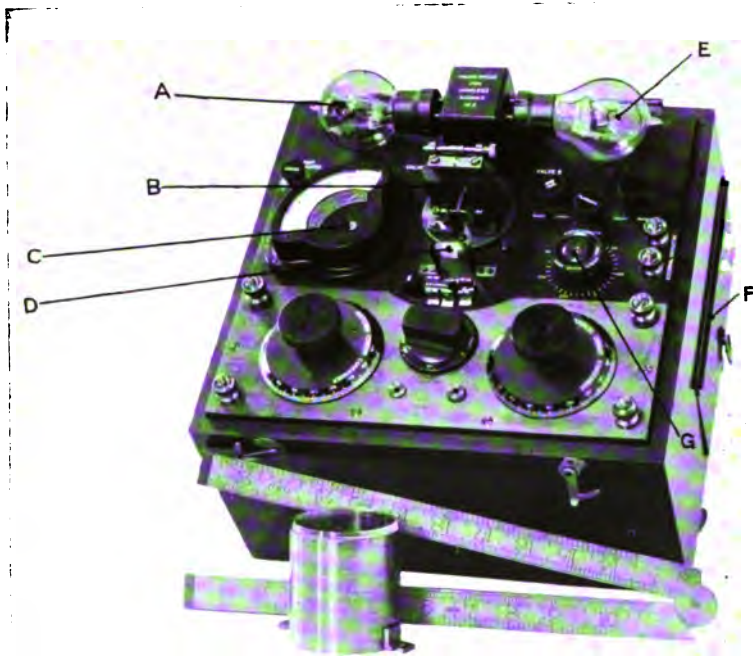


FIG. 87 a.—Turner's oscillatory valve relay.

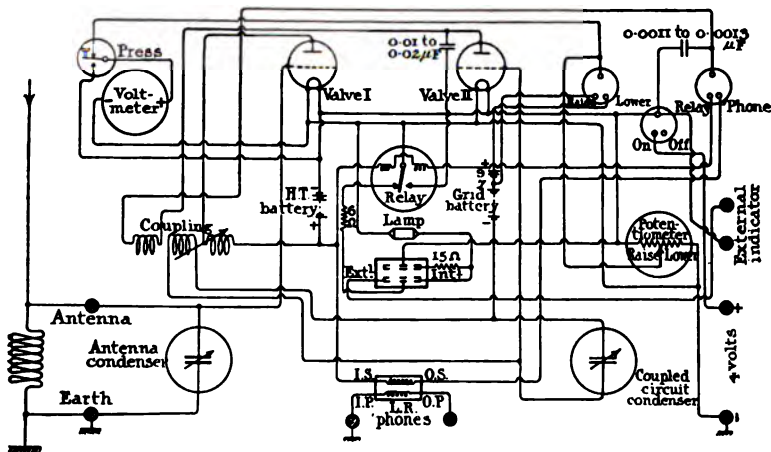
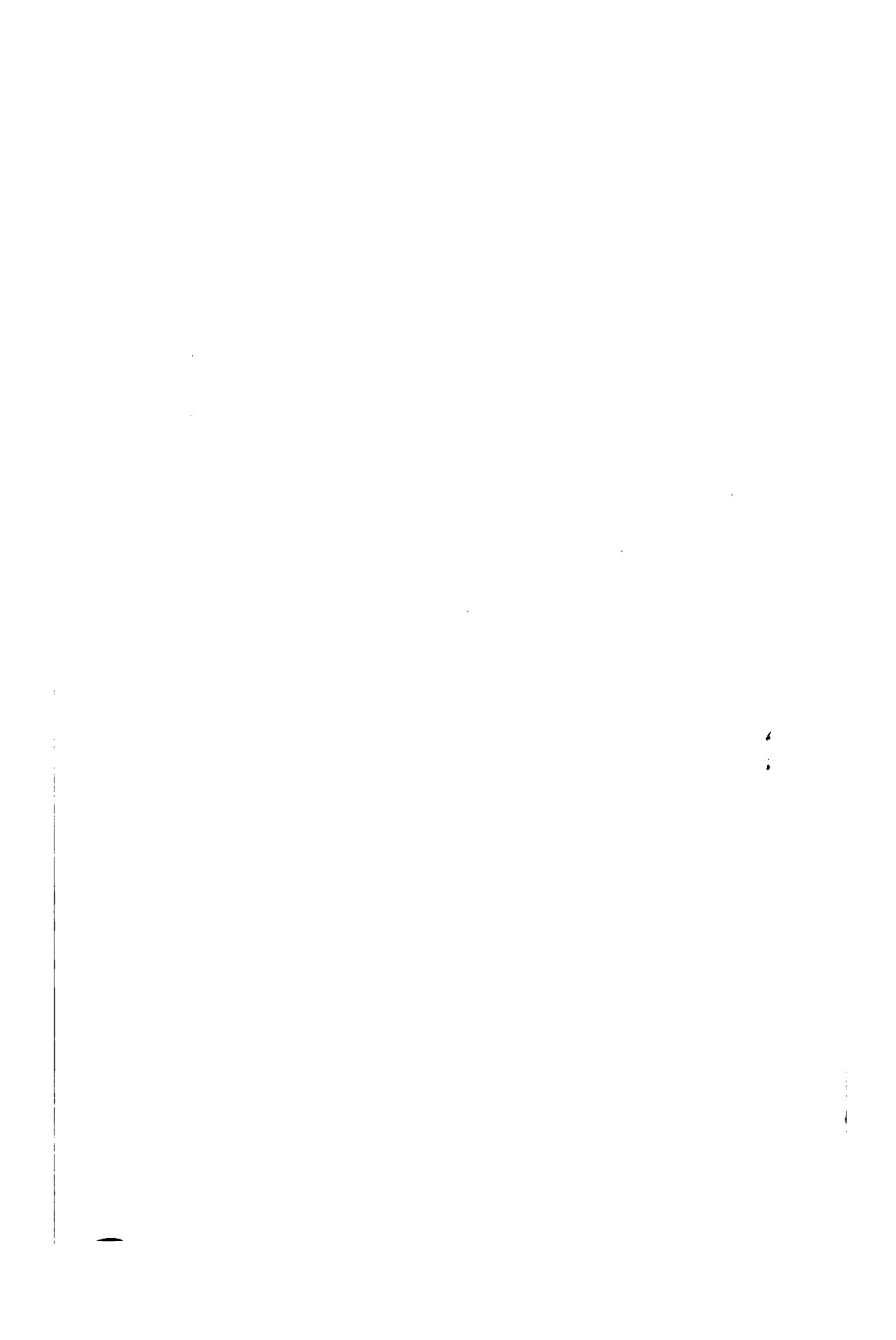


FIG. 87 b.—A valve relay for wireless signals.

1. This valve relay is suitable for C.W. or spark signals of about 1300 to 3200 metres wavelength.
2. When tuning up, set switch to 'phones; raise grid potential (by switch and potentiometer) enough to cause Valve II to generate; and tune in for signals in 'phones, making final adjustment of antenna condenser with loose coupling.
3. Switch over to relay; tighten coupling; and reduce grid potential until relay just ceases to chatter. Readjust coupled circuit condenser (very slightly only), and grid potential.
4. Minimise jamming by having loose coupling.
5. Change of coupling, but not of grid potential, may necessitate slight re-adjustment of closed circuit condenser; but not of antenna condenser.

[To face p. 200.



To prevent the oscillatory valve exciting the aerial and radiating energy a non-oscillating valve A is interposed between the valve B and the aerial, and also serves to amplify incoming signals before they are applied to the oscillating valve.

A further novel feature of this receiver, which Turner has also worked out for ordinary low-frequency line telegraphy purposes, is that it can be used to receive continuous-wave signals without the use of beat, or "heterodyne" reception, or without previous rectification of incoming signals.

Of the further parts lettered in the illustration, C is the grid voltmeter, D a small lamp which can be caused to give a visible record of received signals, G is the valve potentiometer, and F a trap allowing access to the grid and anode batteries.

Turner's paper mentioned above should be consulted for further details.

Other value receivers will be described in Chapters XII. and XIII. of the present book.

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CHAPTER VIII.

SPECIAL APPARATUS FOR TRANSMITTING AND RECEIVER CIRCUITS.

WE have now considered the most important transmitting apparatus and receiving apparatus, both regularly installed in commercial stations, and special apparatus which may require more skilful technique for reliable working.

It will be convenient in this chapter to deal with further special apparatus under the above title, not because any particular apparatus bears any resemblance to the other apparatus in this chapter, but because the apparatus plays a part in both the transmitting and receiving sides of a station and cannot therefore be specially regulated to either side.

THE DUPLEX SWITCH.

In ordinary line telegraphy, duplex and quadruplex working, i.e. transmission of two or four messages along one wire at the same time, is very common and is rendered comparatively easy since the currents used are neither very great nor very small. In wireless telegraphy, however, duplex working is far more difficult, it being necessary to interrupt heavy current circuits and to switch in delicate receiving circuits, so that if any fault should occur the receiver will be rendered useless and possibly the operator injured.

The advantages which may be obtained by overcoming this difficulty is that with duplex working much time may be saved by rendering it possible for the transmitting station to receive signals during the short intervals when the operator is not sending signals, i.e. between the Morse dots or dashes, informing him whether the message being sent is being correctly heard or read, and so to save the time and trouble of repetition of a long message, if any disturbance, such as jamming by a third station, is present. A further advantage is also obtained by the sending operator being able to hear the note of his own transmitter and so to control the same without any removal of his head telephone from the receiver.

One form of Telefunken duplex switch is shown in appearance

in Fig. 88 *a* and diagrammatically in Fig. 88 *b*. The most noticeable feature is the solenoid, 2, which attracts an armature, 3, upon which are three tongues, A, B, and C, which make, by means of flexible connections, contact with a number of platinum contacts, 6 - 6₂ and 7 - 7₆.

The aim of the apparatus is to provide a simple and reliable means whereby, when the signalling Morse key is depressed, the current flows through the solenoid, 2, causing an armature to automatically break all receiving circuits and complete all the transmitting circuits. Directly the Morse key is released gravity causes the armature of the solenoid to fall, break the transmitting connections, and complete the receiving connections. So the apparatus is always automatically at "receiving" when the Morse key is open and the operator may receive messages from an opposite station, without danger to himself or his receiving apparatus.

Dealing first with the lower set of four contacts, the pair 6₂ and 6₃ are directly in the receiver detector circuit. During transmission the tongue C is caused to rise and break this circuit, and to remake, by means of the contacts 7₄ and 7₅, the receiver secondary circuit through an aperiodic circuit and telephone. This enables the operator to hear his own signals and to control the message which he is sending or the tone of the signals.

The centre set of contacts B have an upper pair, 7₂ and 7₃ in the primary circuit of the receiver, which, when the duplex relay is fitted, is in series with the earth and aerial through the tongue B. When signals are being sent, the high frequency currents pass directly to earth, rather than flow through the primary receiving circuit of high inductance and resistance. When the key is released the only path is through the primary circuit and signals can hence be heard.

The low-tension currents operating the transmitting relay in the normal manner, pass through the solenoid, and then to 7 and 7₁ of the upper set of contacts. This solenoid has shunted across it a low resistance, enclosed in a porcelain case seen at the bottom of the illustration, the purpose of which is to permit the bulk of current to pass through it in preference to the high resistance coils of the solenoid which do not, therefore, experience any heating or injury by long use of the apparatus. Although the current does not all pass through the solenoid, this cannot permit the armature to drop while the key is depressed since this would only permit all the current to again pass through and re-energise the solenoid.

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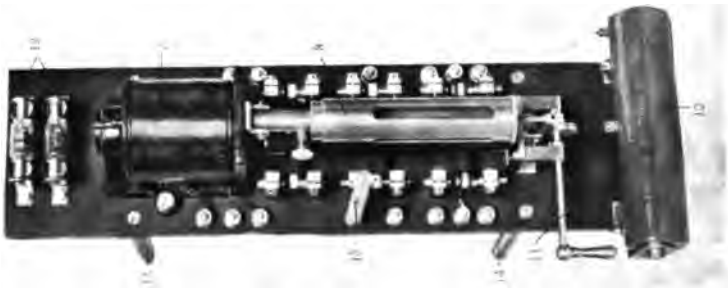


FIG. 88 a.—Duplex switch.

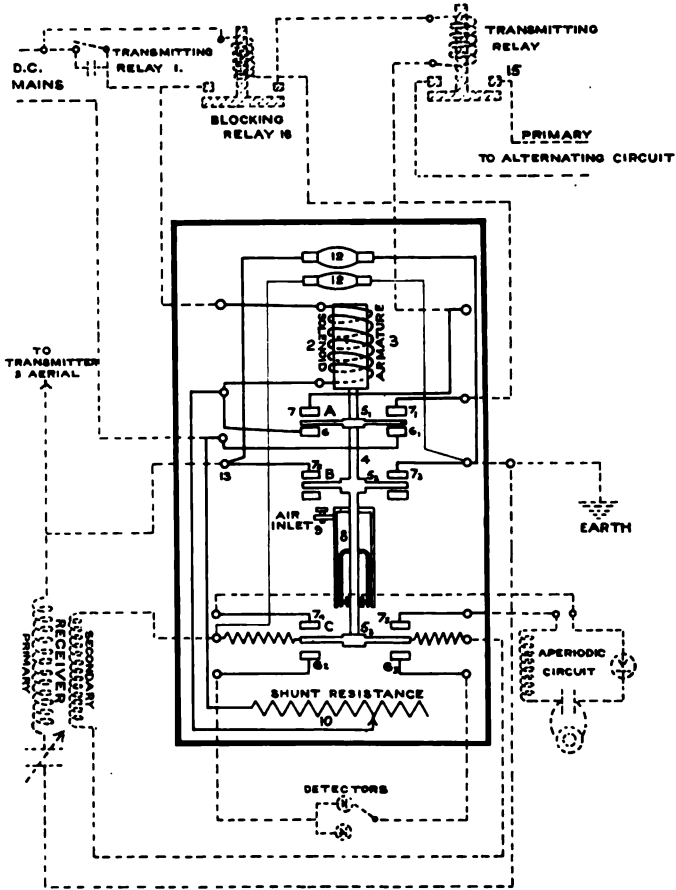


FIG. 88 b.—Connections of duplex switch.

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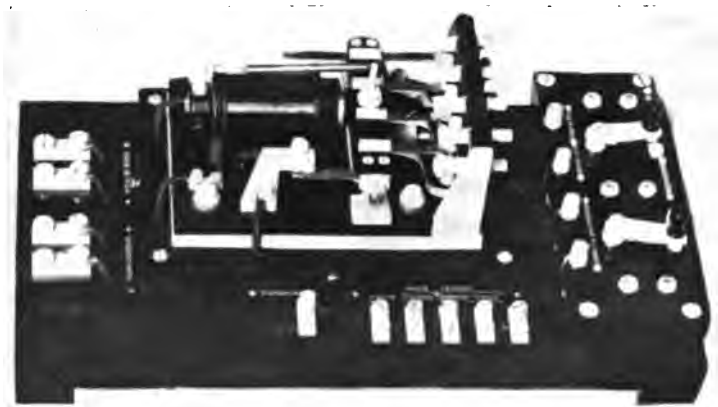


FIG. 89.—Horizontal form of duplex switch. *[To face p. 205.]*

Across the Morse key, which is in parallel with a condenser to prevent sparking, is a shunt circuit in which is the relay to make and break, for signalling purposes, the low-tension alternating current of the transmitter. This circuit may be made to include other relays to switch any accessory receiving apparatus, such as an intensifier, in or out of use during transmission. The lower pair of contacts 6 and 6₁ make the Morse key circuit through the tongue A always complete up to the key, and so the switch is actuated directly this is depressed.

This switch is fixed upon a board of dimensions 20 ins. by 6 ins., which is usually screwed by means of insulators, 14, to the back of the standard receiver, or upon a wall. The earth is connected through the insulator, 13, and the transmitter to the terminal upon the opposite side. At the top of the board are two vacuum lightning arresters, similar to those normally at the back of the receiver, which provide a short circuit path to earth for heavy atmospherics, or protects the receiver if any sticking occurs at the contacts. Since it is often preferable to slightly delay the return of the apparatus to "receiving," and so prevent unnecessary sparking at the contacts and noises in the receiver telephone, a device, 8, is provided. This consists of a cylinder in which a continuation of the armature, 3, works as a piston. When the armature is attracted and rises, a partial vacuum is created in the cylinder, and the armature will not drop until air leaks into the cylinder. The rate of this leakage may be adjusted by the valve, 9, and the apparatus regulated so that the receiving circuits are not made until a certain space of time elapses, and will never drop if the ordinary rate of signalling is continued and the solenoid thereby re-energised. The switch, 11, serves to put the apparatus in or out of use at will, in the latter case alternate receiving and transmitting taking place as if this device were not present.

The above description will show that the apparatus works very simply and effectively, no complicated parts likely to get out of order being present. Reception being impossible during transmitting periods, and vice versa, no danger can occur to the operator.

Several forms of this apparatus are made, the more recent (Fig. 89) being mounted upon a more convenient horizontal board, in which the detectors are directly placed, to remove inductive effects due to long leads to the receiver secondary coil, which may, after continued use of the relay, harm their sensitiveness.

The action of this type is essentially similar to that already

described, but the connections are slightly different and may be found on p. 473, Vol. XXXVI, of the "Electrotechnische Zeitschrift" and in Fig. 130 (22) of the present book.

Other Duplex Methods.—Other methods of duplex working have been proposed, and these may be subdivided into two groups:—

1. Commutator methods.
2. Aerial methods.

Commutator methods of all types suffer from the disadvantage that for the very weak currents received by an aerial, it is absolutely necessary to have a very perfect contact or they are unable to pass. Whilst this can be obtained by a slip ring and brush, for good working, constant attention to the brushes is absolutely necessary. Since, in the relay already described, the weight of the armature is always directed downwards to make good contact with the lower pairs of contacts, such difficulties do not arise with this apparatus.

The first to take out patents for the commutator method was de Forest in 1903 (U.S.A. Patent 772,879) and later Fessenden in 1905 (U.S.A. Patent 793,652).

In these methods the two stations gave prearranged signals, then both sent, and theoretically one sent dots and dashes during the intervals between the dots and dashes of the other.

Marconi in 1908 (British Patent 16,546) modified this method by making the commutator synchronous with his disc-discharger, so ensuring that the receiver was always connected to the aerial, except at the instant when an actual spark was passing across the disc electrodes (a result also possible to obtain by the Telefunken duplex relay).

If, therefore, the two transmitters were run simultaneously, but the sparking periods a little out of phase, since the period taken by two electrodes to pass each other is small, in comparison to the period taken for the next moving electrode to come into juxta-position to the fixed electrode concerned in the previous discharge of the preceding moving electrode, no serious mutilation of signals can result.

For example, if the diameter of a stud electrode to distance between two studs is as 1 to 10, any synchronism cannot mutilate a received dot or dash signal by more than curtailing one-tenth of its length, a shortening which does not render it unintelligible.

The above is the usual description given of this apparatus, but, it should be noticed, it takes the time during which heavy

energy is in the aerial as merely that equal to the period of actual sparking, whereas in reality it is the time necessary not only for the spark to pass but for the energy to be radiated from the aerial. With the Quenched-Spark this time is comparatively long. Doubtless with the rotary gap, since absolute quenching does not result, the damping is great, and therefore the aerial oscillations die out quickly, which gives the desired result for the device, if not for efficiency.

Such an arrangement would be doubtless the best method of duplex working if heavy traffic were really engaged in, but as far as the author is aware there is no station in the world where moderately high-speed work is not sufficient for actual working. The main object of wireless duplex switches is not so much for effecting heavy traffic each way as to enable the sending operator to receive occasional signals during long transmission, so that he knows his own signals are being still received. For such a purpose a relay is quite sufficient.

In dealing with duplex methods of working, Fleming devotes considerable space to the Marconi method, less to the methods of de Forest and Fessenden, and entirely neglects the Telefunken method. Hence his statement that he does not know of any practical duplex working is somewhat vague and hardly carries weight. Contrary to this statement the author knows that not only have practical forms of the Telefunken switch been extensively installed abroad, but an improved form has been manufactured in England and installed on very high-power stations for naval vessels, giving excellent results.

In the author's opinion duplex working of any description, *unless used with automatic transmitters*, should by law be forbidden as dangerous to operators. There is always a danger of transmitting and receiving circuits being short-circuited, however good the mechanical construction, a danger which the author has himself incurred whilst experimenting with such devices. In practice the call for such apparatus is small, as even the largest stations have very little demand for duplex methods because of heavy traffic.

Of the aerial methods it is necessary to mention two only.

Stone in 1901 (U.S.A. Patent 716,136) proposed the use of two sending aerials distant apart a half wave length, between which a receiving aerial is symmetrically placed. In theory mutual interference of the transmitted waves will neutralise their effects at the receiving aerial, a result which does not appear to have been obtained in practice. In any case the

transmitting stations are compelled to use similar equal and constant wavelengths and so to interfere with each other's transmission.

Marconi in 1911 (British Patent 13,020) took out a patent for a method which, it is stated, has been used in transatlantic work and was to be used upon the British Imperial Scheme.

The method is very ingenious and consists of separating the receiver and transmitter over a large distance, which is, however, comparatively short in relation to the range. For example, Devizes was to have been the transmitting station and Oxford the receiving station in England, in order to work with Port Said.

The transmitting apparatus is worked from the receiving

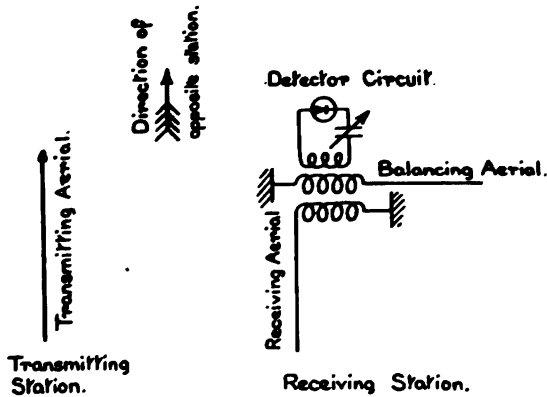


FIG. 90.—Marconi duplex aerials.

station by means of a connected line and relays. At both stations inverted L directive aerials are used, placed so as to radiate or receive in the direction of the distant station. At the receiving station the aerial is joined through the primary of an oscillation transformer the secondary of which is joined to the receiver. A second primary coil is wound on this transformer, and this coil is connected to a small directive aerial known as the "balancing aerial," which is so placed as to receive from the direction of the transmitting station (Fig. 90). The connections and adjustments of the receiving oscillation transformer are such that the effects produced in the main receiving aerial by the transmitting aerial are exactly neutralised by those produced in the balancing aerial. The signals from the more distant station, however, affect the tuned main receiving aerial much

more than the balancing aerial, and thus the detector apparatus is actuated.

This method has had useful practical results, but the objection is that it requires two station buildings, two sets of operators and attendants, two large aerials and a connecting land line between the two stations, with consequent prime cost and maintenance costs.

Now that wireless telegraphy is becoming less conserved, the main expenses of a station are likely to be, in the future, largely due to aerial and mast construction. This, with the additional cost of a special land line and its operation, renders it likely that instead of such a method it would be nearly as cheap to install two separate stations working independently on different wavelengths.

Whilst the very large prices which were to have been obtained for the Imperial Scheme did not make constructional costs of such importance as for ordinary commercial stations, such a method is unlikely to be adopted in preference to using two independent stations should traffic warrant it, and the speed of transmission cannot be increased sufficiently.

Furthermore, in such countries as South America it might be impossible to lay or maintain the connecting line between receiving and transmitting stations. Further information regarding duplex working, as applied to valve transmitters for use in aircraft, will be found in Chapter XII.

THE WAVEMETER.

The wavemeter is the most important instrument used in wireless practice for the control of the transmitting and receiving circuits. It comprises the qualitative functions of both the aperiodic circuit and buzzer, as well as permitting quantitative measurements of electrical quantities, important for both purely wireless and purely physical reasons.

It has been seen that under certain definite conditions a circuit having inductance and capacity will oscillate electrically and give rise to distant electrical disturbances, which may be demonstrated by suitable means in a circuit having the same frequency of oscillation as that giving rise to the disturbances—in other words, the two circuits must be “tuned” to each other and have the same wavelength.

If we have an oscillatory circuit, such as a wireless excitation circuit, and require to measure its wavelength, this can be carried

out by permitting it to induce upon a circuit of known capacity and inductance, either of which may be changed until oscillations are produced in the latter circuit. Then by means of the formula $\lambda = 2\pi \sqrt{LC}$ the wavelength of this circuit and hence of the excitation circuit may be determined, a more refined value being obtained if allowance is made for the resistance of the measuring circuit.

To detect the oscillations in the wavemeter circuit three chief methods are used. These are:—

1. By use of a wireless detector and telephone, the wavemeter playing the part of an ordinary wireless receiver, maximum intensity of signals indicating resonance between the two circuits. A crystal or thermionic valve may be used as detector.

2. By use of a helium tube, which has the property of being rendered luminous by electrical oscillations, or of a small lamp which will also be illuminated, maximum luminosity showing resonance.

3. By use of a hot-wire indicating instrument, such as an ammeter or wattmeter, which, at the point of resonance, will give maximum reading.

The first two methods do not permit of such refined quantitative measurements being taken as occurs by the use of the third method. In the above methods the wavemeter is used to receive oscillations. It may also, if its circuits be excited by means of a buzzer, be used to send oscillations, and if these are detected by one of the above methods the wavemeter is capable of use to test receiving circuits. Such a use was first suggested by Dr. Eichorn of the Telefunken Company, and forms the subject of the German Patent No. 217,339.

Dealing with the general construction of the wavemeter it would, of course, be very uneconomical to have to provide a separate oscillatory circuit for the determination of each particular wavelength. The instrument must therefore be provided with a wave range, and this may be obtained by two methods: (1) by variation of the inductance, (2) by variation of the capacity. The first method was used by Professor Slaby of the Telefunken Company, who invented the first wavemeter, known as the Slaby Measuring Rod. Modern wavemeters, however, make use of the second method since, by means of a movable-vane condenser, variation of capacity is much easier than variation of inductance. Various fixed inductances are used, however, to obtain different wave ranges, between the limits of which continuous variation is obtained by means of the variable condenser.

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FIG. 91.—Telefunken wavemeter in transport case.

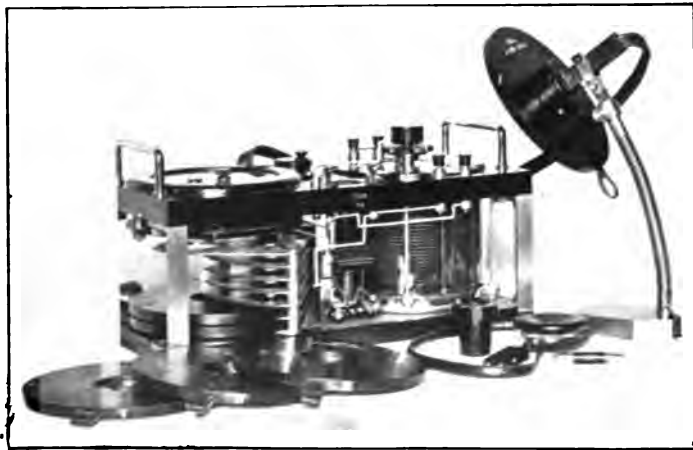


FIG. 92.—Telefunken wavemeter assembled for use.
[To face p. 211.]

Possibly the most elaborate wavemeter manufactured commercially is that of the Telefunken Company, known as the Universal Wavemeter, which may be used for the most refined wireless and physical measurements. The instrument is shown packed for transport in Fig. 91 and assembled for use in Fig. 92. The oscillatory circuit is formed by the variable condenser and one of six inductance coils.

The condenser consists of a set of fixed plates between which a second set of plates can be caused to rotate by means of the handle at the top. A double-ended pointer fixed to this handle moves over a scale, from which the degrees of rotation may be read after the production of resonance and the corresponding wave length then read from calibration curves provided. The other pointer carries a small window with a hair line which enables approximate wavelengths between 400-3400 meters to be directly read from three scales. The condenser has an oil dielectric, and is protected from injury, if too strong oscillations are induced within it, by means of a small spark-gap, between which a spark passes without damage, instead of between the condenser plates.

The inductance coils are formed of flat coils of finely divided wire, of 120 or 240 strands, in order to diminish the resistance, and therefore the damping of the oscillations. Each coil can be placed in a flexible spring support, and so used as an exploring coil to obtain the most suitable coupling between the wavemeter and circuit being tested. Upon each coil are three contacts, two of which connect the whole length of the coil and one connects part of the coil to the indicating wattmeter, as shown in Fig. 93. These coils have the contacts so arranged that they can only be connected to the body of the instrument in the correct position. Six coils are provided, giving wave ranges as follows: (1) From 90 m. to 260 m.; (2) from 180 m. to 500 m.; (3) from 400 m. to 1050 m.; (4) from 650 m. to 1800 m.; (5) from 1200 m. to 3400 m.; (6) from 2100 m. to 5700 m., and each coil has a mean damping of .015 which must, however, for the most refined work, be directly determined, according to a method given subsequently, by insertion of a resistance in the terminals provided for this purpose, which are otherwise short-circuited.

A small switch enables the wattmeter to be used when upon a particular stud, the detector and telephone, or helium tube, to be used when upon a second stud, the indicator not required in this case being previously removed. Two other studs are present,

one of which enables the buzzer to continually excite the wavemeter when this is being used as an oscillator, and the other enabling Morse signals to be given by depressing it, the stud not continually making contact with the switch. This buzzer is actuated by dry cells fixed in the apparatus. All the accessory apparatus and spares are packed for transport within the lid of the containing case.

This wavemeter is undoubtedly the most accurate and elaborate wavemeter yet manufactured.

For less refined measurements, such as for tuning small stations, a smaller type of wavemeter is used. This is identical in principle, but a small glow-lamp replaces the hot-wire wattmeter of the larger wavemeter. It is illustrated in Fig. 94, and the particular parts visible should be easily recognised from the

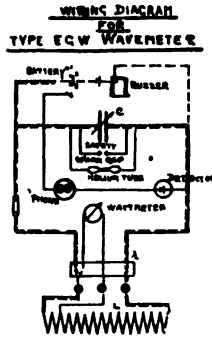


FIG. 93.—Connections of wavemeter.

foregoing description. A still smaller form of wavemeter, known as a Station Tester, is shown in Fig. 95. In this form the majority of the apparatus, buzzer, etc., are placed within the wooden case. An helium tube is used to indicate resonance and is visible through a slot cut in the lid. The inductances are wound upon three interchangeable drums fixed to the top of the apparatus, and a separate exploring coil is used.

WAVEMETER MEASUREMENTS.

As already mentioned the wavemeter is the most important measuring instrument used in wireless telegraphy, and the measurements which can be carried out by it are manifold.

The most important determinations which a wireless engineer has to carry out with such an instrument as the Universal Wavemeter will here be dealt with.

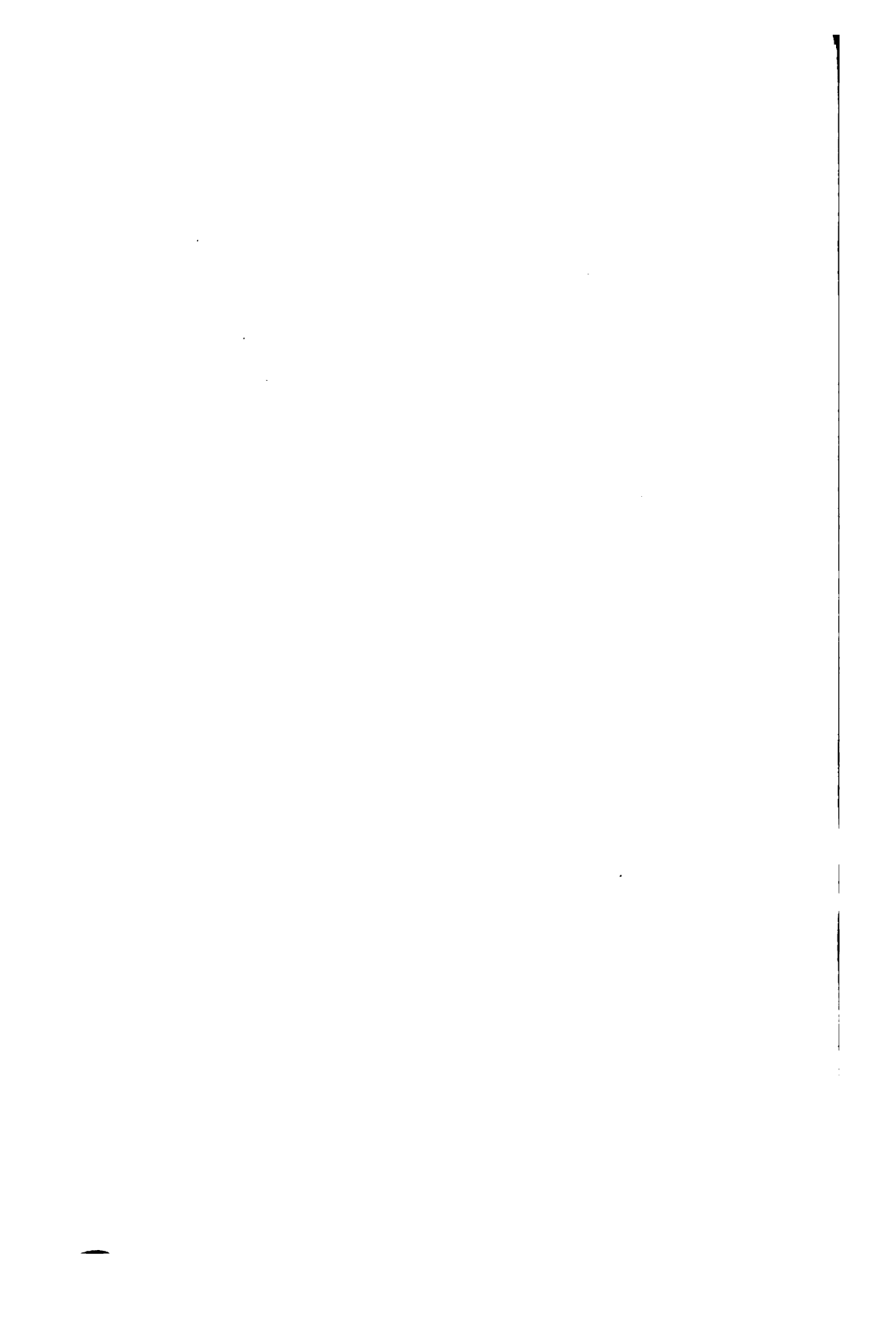


FIG. 94.—Small wavemeter.



FIG. 95.—Station Tester.

[To face p. 212.



Determinations of Wavelengths and Coupling.—1. *Wavelength of an Excitation Circuit.*—The exploring coil of the wavemeter is placed near to the excitation circuit, and is used as a receiver; that is, oscillations are induced in the wavemeter by oscillations in the excitation circuit.

The intensity of these induced oscillations is varied by increasing or decreasing the distance between the wavemeter and circuit according as to whether weak or strong induced signals are desired, the former having the advantage of permitting more exact tuning, and also diminishing mutual induction between the wavemeter and circuit which causes alteration of the former's wavelength. The excitation circuit is then worked in the normal manner and the induced oscillations in the wavemeter (the wavelength of which is varied by means of its condenser) may be detected either by use of the hot-wire wattmeter, which gives maximum reading for maximum resonance; or by the helium tube, which glows during resonance; or by a detector and head telephone, which gives maximum sound when resonance is obtained between the two circuits.

The helium tube method is that commonly used for practical determinations. Should no result be obtained it is either necessary to increase the coupling, i.e. to approach the wavemeter nearer to the excitation circuit, or as the excitation circuit wavelength may not be within the range of the particular exploring coil it may be necessary to change this until the correct coil is discovered. When the indication of resonance is most intense the wavelength of the wavemeter is the same as that of the excitation circuit, and may be read either directly from the scale upon the variable wavemeter condenser or by means of calibration curves provided for this purpose.

2. *Wavelength of an Aerial.*—The wavemeter may in this case be used either as an oscillator or a receiver. In the latter case the aerial is excited as a "plain aerial" (see Fig. 96) and the wavelength measured as above. This method is objectionable owing to the presence of the spark gap causing the oscillations to be heavily damped.

A better method is to excite the aerial by means of a buzzer (Fig. 97) connected to the coupling turns, and to use the wavemeter as a receiver, with a detector and telephone as indicator.

As a further alternative, the wavemeter may be caused to induce upon the aerial as an oscillator (by use of the buzzer of the wavemeter) which is varied until maximum signals are heard *in the aerial* by means of a detector and telephone. In both

cases the wavelength is read at the point of maximum sound, and it is necessary to take precautions so that the buzzer does not directly induce upon the aperiodic circuit of the detector and telephone, which gives rise to a continuous sound in the telephones without any maximum.

3. *Wavelength of a Receiving Circuit.*—This is carried out according to the last two methods given, the only difference being that the aperiodic detector circuit is now formed by the secondary coil circuit of the receiver, which should be as loosely coupled with the primary coil as possible. The same precautions against direct induction from buzzer to aperiodic circuit applies to this test.

4. *Wavelength of a Receiver Secondary Circuit.*—This may be determined by rotating the secondary coil as far as possible

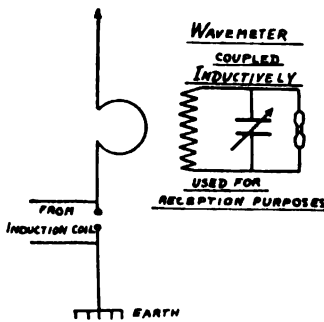


FIG. 96.

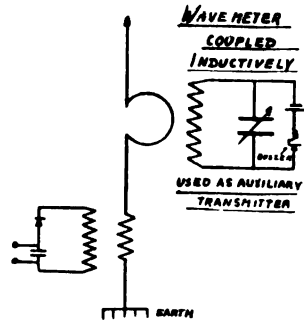


FIG. 97.

from the primary coil, which is excited by means of the wave-meter, producing maximum sound in the telephone of the secondary circuit when the wavelengths of each circuit are identical, that of the primary circuit being already determined by method 3. The coupling between secondary coil and wave-meter exploring coil should first be made tight and then reduced as far as possible.

5. *Wavelength of a Distant Transmitting Station.*—For this measurement the receiver of the one station is accurately tuned to receive the signals of the distant transmitting station. The wavelength of the receiver is then measured as above, and is necessarily equal to that of the distant station.

6. *Coupling between Excitation and Aerial Circuits.*—This may be obtained by measuring, by the methods already given, the natural wavelength λ_0 of either the excitation or aerial

circuit, when these are uncoupled and of equal wavelength. The effect of coupling the two circuits together is to produce two oscillations of wavelengths λ_1 and λ_2 , which are each measured by the wavemeter, and the coupling K is then given as a percentage by the formula—

$$K = \frac{\lambda_1 - \lambda_2}{\lambda_0} \cdot 100.$$

When determining the coupling of Quenched-Spark transmitters it will be found necessary to replace the quenched gap by an open gap, owing to the quick quenching of the oscillations in the excitation circuit. If a curve showing the relation being the square of the current in the wattmeter of the wavemeter

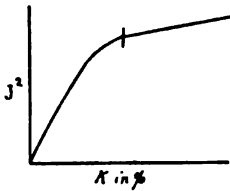


FIG. 98.

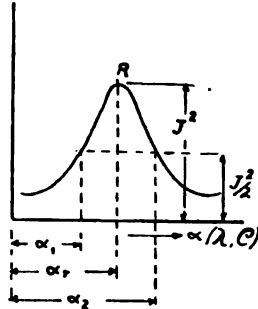


FIG. 99.

(i.e. the direct readings) is plotted with various couplings as abscissæ it will be of the form shown in Fig. 98. The best coupling for the transmitter is that given by the point just beyond the bend of the curve. This is about 20 per cent., and holds good for use with transmitters having wavelengths up to 2000 metres and a ratio of excitation circuit capacity to natural aerial capacity of 25 : 1.

Determinations of Damping.—1. *Damping of a Simple Excitation Circuit*—i.e. *Circuit with Spark Gap*.—Measurements of damping being quantitative, it is necessary to use the hot-wire wattmeter for these determinations, since this gives quantitative and not comparative readings like the detector and helium tube methods. To determine the damping of a circuit it is necessary to obtain a series of wattmeter readings—i.e. readings proportional to the square of the current, and plot these against the wavelength or condenser readings in degrees as

abscissæ. The curve so obtained will be similar to that shown in Fig. 99. Any line is then drawn parallel to the x axis, and values a_1 and a_2 taken where a_r is that value corresponding to the maximum.

Then, according to a method due to Bjerknæs, d_1 , the damping is given by—

$$d_1 = \frac{\pi(C_2 - C_1)}{2C_r} \text{ or } = \frac{\lambda_2 - \lambda_1}{\lambda_r} = \frac{\pi(a_2^0 - a_1^0)}{2a_r^0},$$

where the values of a are in degrees, as read from the instrument. To this formula two corrections must be made: (1) To correct for the zero error of the condenser the readings of which at the beginning of the scale are not exactly proportional to the angle of rotation. This for a Universal Wavemeter is 4° and cancels in the expression $a_2 - a_1$. (2) The natural damping d_2 of the wavemeter must be subtracted from the total damping of wavemeter and tested circuit. The result is therefore—

$$d_1 = \frac{\pi(a_2 - a_1)}{2(a_r - 4^0)} - d_2$$

from which, if d_2 is determined by the method next given, d_1 is known.

Precautions must be taken in the determination to avoid the coupling between wavemeter and circuit being too great. If this is the case the value of the damping will be too great and the coupling should be varied until a constant value is obtained.

2. *Natural Damping of the Wavemeter.*—The measurement given above must first be carried out and the value of ($d_1 + d_2$) so obtained.

A non-inductive resistance W is now inserted in the wavemeter circuit by means of terminals provided (Fig. 100). The insertion of this resistance lowers the previous reading I_{r1}^2 to I_{r2}^2 , and the resistance should be chosen to make the latter about one-half of the previous value.

Then calling the new total damping Δ ,

$$\Delta d_2 = \frac{2}{300} \frac{CR}{\lambda}$$

where R = resistance in ohms. of W .

C = capacity in centimetres of wavemeter at maximum reading.

λ = wave-length in metres of wavemeter at maximum reading.

The value of d_2 can now be found from the expression—

$$d_2 = \frac{\Delta d_2}{\frac{I^2_{r1} (d_1 + d_2)}{I^2_{r2} (d_1 + d_2 + \Delta d_2)}}$$

It will be found of advantage to arrange so that d_1 is greater than d_2 or Δd_2 by the introduction of a suitable non-induction resistance in the wavemeter circuit. The ratio

$$\frac{d_1 + d_2}{d_1 + d_2 + \Delta d_2}$$

will then tend to unity and the value of d_2 tend to

$$d_2 = \frac{I^2_{r1}}{I^2_{r1} - I^2_{r2}} \Delta d_2$$

in which case d_1 is made at least ten times d_2 by use of an electrolytic resistance inserted in the wavemeter.

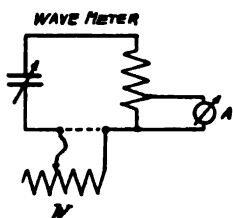


FIG. 100.

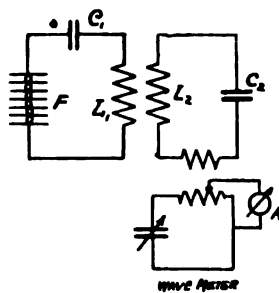


FIG. 101.

3. *Damping of Circuit without Spark Gap, i.e. an Aerial Circuit* (Fig. 101).—The circuit is excited by a Quenched-Spark excitation circuit with a coupling of 15 to 20 per cent., and the damping found by the method already given under 1. Since this form of circuit is only very weakly damped, the value of d_2 used for the wavemeter must previously be very accurately found by the method just given.

4. *Damping of a Coupled System, i.e. of Combined Excitation and Aerial Circuits.*—Two waves are present in such a system—one above and one below the common wavelength. With an open-spark transmitter these waves can readily be detected, and as the resonance points do not greatly differ from each other, either part of the curve can be used to obtain the approximate

damping according to method 1. With a Quenched-Spark transmitter, however, the resonance points differ very considerably with a loose coupling. A non-inductive resistance R (Fig. 102) must, therefore, be inserted in the aerial circuit to increase the damping of this circuit, and the method followed, as in the determination of the wavemeter damping.

Capacity Determinations.—1. *Relative Damping of a Condenser.*—It is often necessary to determine the relative dampings of condensers. This may be carried out by use of the wavemeter as an oscillator, exciting a circuit in which either a standard condenser or the condenser under test may be inserted by a two-way switch (Fig. 103). An aperiodic circuit is coupled to this circuit, having a ballistic galvanometer in place of a telephone, and throws are obtained upon this with either condenser

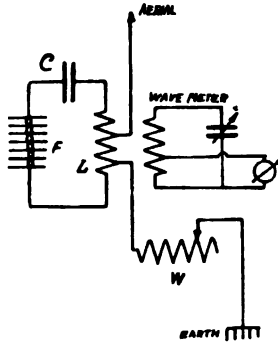


FIG. 102.

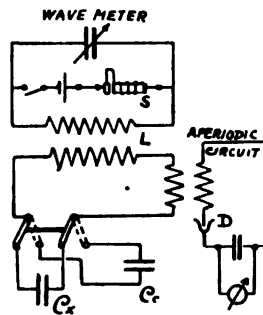


FIG. 103.

in circuit. The dampings of the condensers will be inversely, as the readings of the galvanometer, and they may thus be compared. It is important to see that either of the two inductive couplings do not vary during the test, and the inductance of the oscillatory circuit has small damping.

2. *Capacity of an Aerial.*—The aerial is connected as a "plain aerial" (Fig. 104), and its natural wavelength λ_A determined as already explained. An inductance L , and capacity C , are then alternatively put into circuit, and corresponding wavelengths, λ_L and λ_C obtained.

If these do not greatly differ from the natural wavelengths, it is permissible to write the capacity K_1 of the aerial with inserted capacity—

$$K_1 = C \frac{(\lambda_A^2 - \lambda_C^2)}{\lambda_C^2}$$

which tends to

$$2C\left(\frac{\lambda - \lambda_c}{\lambda_c}\right)$$

and the capacity K_2 of the aerial with inserted inductance—

$$K_2 = \frac{\lambda_L^2 - \lambda_a^2}{4\pi^2 L}$$

which tends to

$$\frac{\lambda L(\lambda_L^2 - \lambda_a^2)}{20 L}$$

and from which the natural capacity K_s can be obtained, since

$$K_s = \frac{K_1 + K_2}{2}$$

3. *Simple Determination of Capacity.*—A substitution method

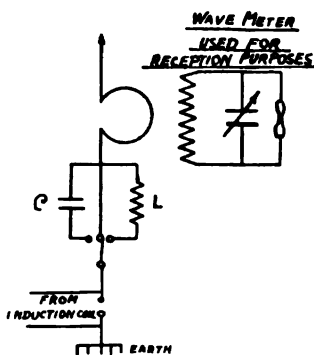


FIG. 104.

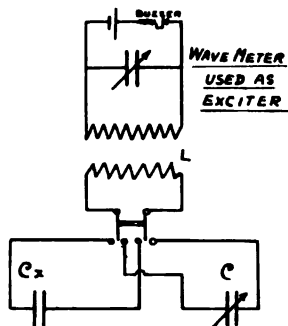


FIG. 105.

is available for the approximate determination of capacity by means of the wavemeter. An unknown condenser C_x is first put into circuit with an inductance, and the wavelength of the circuit is obtained by use of the wavemeter as oscillator, and an aperiodic circuit with telephone (Fig. 105).

The standard condenser C is now put into circuit, and this condenser is varied until sounds of equal strength to those with the other condenser are obtained. The value of the capacity of both condensers will then be equal if the couplings are maintained constant.

A second method, similar to that later given for inductance measurements, is also available if a known inductance is used.

Further Wavemeter Determinations.—1. *Testing Detectors.*—For this purpose the wavemeter is used as an oscillator, and induces upon a receiver tuned to the same wavelength. A standard and unknown detector are then alternately used with the receiver, and comparative tests for extinction of the telephone signals carried out either by variation of coupling, when the most sensitive detector will be just heard with a weaker coupling, or by adjustment of a resistance in parallel to the telephone. The lower the resistance needed to just extinguish signals, the more sensitive will be the detector.

2. *Control of the Note of a Transmitter.*—For this purpose the loosely coupled wavemeter is used as a resonator with detector and telephone, and adjustments to the transmitter can then be carried out to give the most musical note in the telephone.

3. *Measurement of Inductance.*—A closed oscillating circuit is formed of a known capacity C and unknown inductance L. An aperiodic circuit is then used to receive signals according to the method given for determination of damping of condensers. Using the wavemeter as an oscillator, the wavelength of this circuit is determined and the inductance calculated from the expression—

$$\lambda = 2\pi\sqrt{LC}.$$

This method is not strictly accurate, since no account is taken of the damping or the mutual inductance between the test circuit and aperiodic circuit. It gives, however, results sufficiently accurate for practical purposes. With a known variable inductance, capacities can conversely be measured. Inductances can also be compared by the substitution method given for capacity.

[With acknowledgments to a pamphlet "Der Grosser Wellenmesser," issued by the Telefunken Company, of which the above is practically a translation rearranged.—AUTHOR.]

DIRECTIONAL WIRELESS TELEGRAPHY.

During the past decade considerable attention has been directed towards directional wireless telegraphy, since by this means a ship at sea could locate its position during fog, etc., and during the more recent years, enemy aircraft, ships, and submarines could so be located.

It is interesting to review briefly the historical aspects of

wireless directional work, since it will be seen that the objects of this branch of telegraphy have been completely reversed.

In the earlier work the aim was to concentrate, the otherwise spherically wireless transmitted energy, to a specific direction in order that more energy would so be sent to a receiving station, and more of the transmitted energy would be so utilised in useful work.

At the present day this aim has been nearly entirely dropped, and the problem is that of locating the transmitting station for purposes given above.

Hertz was the first to discover that by means of reflection by parabolic mirrors, electro-magnetic waves could be brought to a focus exactly as in the case of analogous light waves.

Marconi, in his patent of 1896, included the work of Hertz within his specification as a means of directing the energy transmitted from an aerial.

Many other observers utilised such a means of reflection in the early days when wireless transmission was only conducted over one or a few miles. The increase in range of wireless stations necessitated a corresponding increase in size of the reflecting apparatus, which soon became unwieldy and impracticable.

The next phase of directional work is concerned with the application of interference phenomenon as occurs in light, by utilising two or more mutually interfering aerials.

The earliest recorded method is that of the lesser known pioneer of wireless in England, S. G. Brown, who in 1899 patented a method in which two vertical aerials were used, distant a half wavelength from each other. When these were connected with a phase difference of 180° in the oscillatory periods, the effect was to cause radiation in the plane at right angles to their own plane, and theoretically not in other directions.

Braun, in 1904, patented in Germany practically a similar method and then extended it to use three vertical aerials situated at the corners of an equilateral triangle, whereby by means of phase differences the aerial oscillations were caused to assist each other in a single direction and to mutually interfere in other directions.

Such methods as the above, although theoretically sound, were practically of little use, and de Forest and many others developed closed aerials, mounted on frames which could be rotated to give best radiation in any particular direction.

About 1906 Marconi in England, Sigsfeld in Germany, and many others, found that by use of an inverted L aerial

propagation occurred best towards the foot of the L or lead-in wire, to a lesser extent in the reverse direction, and still less laterally.

This type of aerial was in England called the "Marconi Directional Aerial," but its use, usually for ship stations, is general throughout the world, and although patented, no action is ever likely to be brought against its use by others. According to Eccles its directional properties do not possibly exist at distances slightly removed from the aerial, a statement largely borne out in practice, which shows its directional effects to be very small.

With the increase in ranges and wavelengths the use of rotating aerials rapidly became mechanically impossible.

From this period directional work is largely in one of two directions :—

1. By means of a number of L aerials set out along the points of a compass and therefore known as wireless compasses or radiophares, since their use is analogous to that of a lighthouse (French ; phare = lighthouse), except that electrical instead of light rays are used.

2. By means of an instrument known as a "goniometer," i.e. an instrument which measures angles, such angles being determined by the directions from which electrical waves are received.

The first method was developed by the Telefunken Company, and the latter method by Artom in Italy, although more often known as the Bellini-Tosti compass, since these two investigators developed its uses, finally selling their rights to the Marconi Company.

The Telefunken Compass.—In the first form of this apparatus devised at the instance of the Prussian Ministry of Works, the aerial consisted of 32 single wire aerials radiating from one high mast to 32 low masts, arranged upon the circumference of a circle 200 metres in diameter. The single wire aerials were all brought to a circle of insulators upon a support, which may be seen above the ordinary transmitting apparatus in Fig. 106. These insulators carried metallic slotted spheres, in the slots of which a rotating switch, moving round the pillar support, made contact, the switch being rotated by gearing worked by a small motor seen near the support. Contact to this switch from the transmitter was made by means of two brushes, which may be seen working against slip rings upon the upright support. Each pair of directly opposite aerials were successively put into contact by the switch, and transmission took place upon them, each

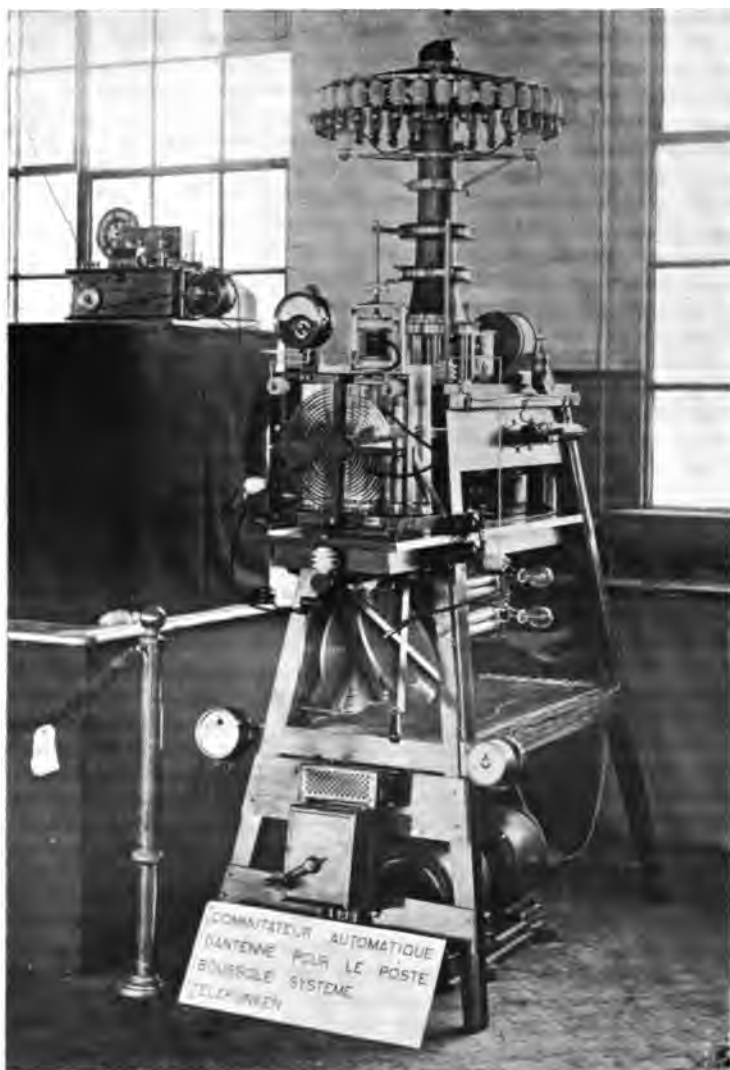


FIG. 106.—Telefunken Compass installed at Woolwich for experimental purposes.
[To face p. 222.]

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pair giving out a particular signal, such as a letter, by use of an automatic transmitter.

If an ordinary acoustic receiver with undirective aerial is placed in the plane of the pair of wires which are in operation at any particular time, then the receiver obtains the maximum energy, the half wavelength being chosen so as to be about equal to the distance apart of the masts. If, on the other hand, the receiver is accurately at right angles to the plane of the mast pair in use, the oscillations received are opposite in phase and counteract each other.

The receiving operator must determine in the telephone which letter is loudest or softest. The position of the transmitter is shown on a chart as well as the respective aerial pairs and their different letters. If two such transmitters are at a certain distance apart the receiver can determine their respective directions and so show them on the chart that the intersection of these lines will give the actual position of the receiver at the moment.

With the foregoing arrangement it was necessary for the operator to note not only the intensity of the signal, but also its distinguishing letter. Increase in the number of aerials would enable more exact determination of the position of the moving station, but would entail greater skill upon the part of the operator in order to at the same time both measure and distinguish an increased number of signals.

In order to overcome this difficulty a simple device is adopted. The aerial of the transmitting stations is made in an umbrella form, each wire of which is broken and insulated according to the method shown in Figs. 107 and 108. The lower parts of the wire give the necessary directive aerials, and the upper parts a non-directive umbrella aerial.

The receiving operator is provided with a stop-watch, marked with the cardinal points of the compass instead of in seconds. A separate signal is now given at the transmitting station upon the non-directive aerial, and the receiving operator starts the stop-watch. As soon as he hears the single dot of the strongest or weakest signal he stops the watch, and the hand then indicates the direction of the particular pair of aerials giving the signal, providing the switch connecting the aerial pairs is synchronous with the hand of the stop-watch and both start from the same point of the compass.

By such a method a large number of results can be quickly taken, the mean of which will be very accurate. The hand of the

stop-watch making one revolution per half-minute, ten determinations can be made within five minutes, and the mean so obtained will give for wireless position determinations a very accurate result, the error in the angle between two fixed stations being correct within 2 or 3 degrees. There is, further, no need of intercommunication between the sending and receiving stations if the former has once commenced to work.

This method of determination of position has been adopted in Germany for the determination of the positions of airships during fog, etc. A chain of stations are erected around the coast and frontier, so that airships cannot leave Germany without the knowledge of the aviators. They work automatically, and the aerials are fixed to smoke stacks near towns from which they can

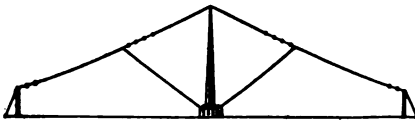


FIG. 107.

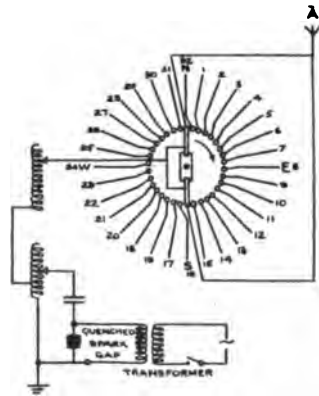


FIG. 108.—Arrangement of aerials for Telefunken compass.

obtain the necessary electrical energy, which is 0.5 kw. per station.

Owing to the aerials of each station being arranged around the points of the compass, this apparatus has been called the Telefunken Compass. Its advantages are evident; any ship provided with a stop-watch, which is the only additional apparatus required at the receiving station, can make use of it. Long aerials can be obtained giving an advantageous wavelength upon which the radius of transmission, fixed by the International Radio-telegraphic Convention at 50 miles, can easily be obtained with low-power installations. This limit in the range of these "radiophares" is made in order to prevent such stations from proving a source of annoyance to other stations engaged in ordinary wireless communication.

This radiophare method was used by the Germans during the war in order to permit their submarines to determine their positions, without transmitting and so betraying their positions to our interception stations.

According to Addey, just before the war, the French Government, which had investigated both the radiophare and goniometer methods of directional work had decided to install a system of radiophares around the French coast to enable ships to determine their positions.

The Goniometer.—This is an extension of the old rotating frame method already described, but by an ingenious device the objection to rotating the aerial is overcome.

If a frame aerial is at right angles to the transmitting station, the currents induced in each vertical limb will be exactly in phase and will so balance each other, and no resultant current is obtained.

If, however, the frame aerial is "end on" to the transmitting station an incident wave front encounters the two vertical limbs at slightly different instants due to the period necessary for the wavefront to travel from the limb first met to the slightly more distant limb.

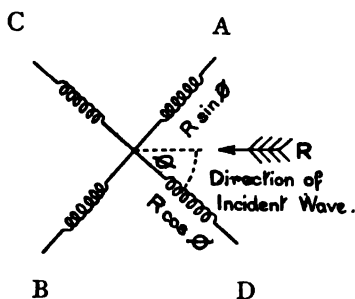


FIG. 109.

The current in each limb therefore differs in phase from each other (unless their distance apart is exactly a multiple of the wavelength) and a resultant current therefore flows in the frame.

Artom overcame the necessity of rotating the aerial by the use of two similar aerials rigidly fixed, and comparing the effects in each by connecting in each frame an inductance coil and comparing the resultant fields by means of a small rotating secondary coil.

The means by which this is carried out is realised if we represent the two oscillatory circuits, formed by the frames, by the conductors AB and CD (Fig. 109), and consider an incident wave in the direction shown by the arrow making an angle θ with AB.

The energy of the incident wave will be resolved into two current components proportional to $\sin \theta$ for the conductor AB and proportional to $\cos \theta$ for CD.

If now these currents are led to two small coils at right angles to each other, they will set up alternating magnetic fields which will also be proportional to $\sin \theta$ and $\cos \theta$ in each case.

Such component magnetic fields will have a resultant whose sum will be $\sqrt{(E \cos \theta)^2 + (E \sin \theta)^2}$ and whose direction will be an angle whose tangent is $\frac{\sin \theta}{\cos \theta}$, i.e. an angle identical to the angle of incidence θ .

Since this magnetic field is alternating and its greatest value must necessarily be at an angle θ , we can determine θ by use of a small rotating coil, in which currents will be induced and can be measured by an aural detector or otherwise.

By noting the most intense reception of signals we can so directly determine θ . In practice, however, since it is easier to correctly judge slight differences of signal strength with weak signals than with strong signals (an effect known as Weber's Law in physiology) it is preferable to find the position of the rotating coil which give weakest or absent signals and then, by adding 90° to this angular rotation, the position of strongest signals is determined.

Such an exploring coil only gives the direction of signals and not the sense of direction. This was overcome by also erecting a small vertical aerial at the common axis which could be combined with either frame aerial upon wish, and in one case the current would be due to the additive effect and therefore give increased signals and in the other case due to a subtractive effect giving weaker signals, so that the sense of the incident wavelength was determined. In most determinations of direction the sense is known and the use of such a vertical aerial is unnecessary, or can be overcome when the receiving station is moving at an approximately known velocity by taking two consecutive measurements.

The actual apparatus for use with such perpendicularly placed aerials (Figs. 110 *a* and *b*) is therefore very simple and consists of two perpendicular windings, between which, either internally or externally, a secondary rotating coil can be rotated (Fig. 111).

The secondary coil windings can be taken to either a crystal or valve receiver to measure the intensity of induced signals.

This method, by replacing the receiver by a transmitter, can be used for transmitting directional signals.

The aerials will naturally give better results if inductance or capacity is inserted to tune them to incoming waves.

Comparison of Radiophare and Goniometer Methods.— Both arrangements have particular advantages, but the balance of advantages are in favour of radiophares, and are chiefly :—

1. *Economical.*—Since the large majority of wireless stations are ship stations greatly outnumbering coast stations, to equip

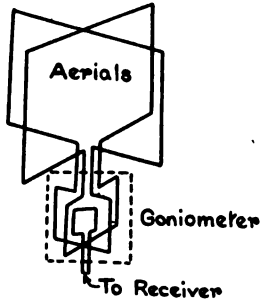


FIG. 110 a.—Goniometer circuits.

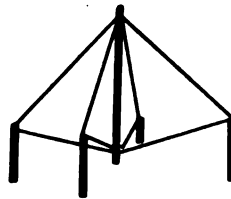


FIG. 110 b.—Goniometer aerials.

such vessels in order to enable them to obtain their positions of the goniometer method, means the installation of a greater

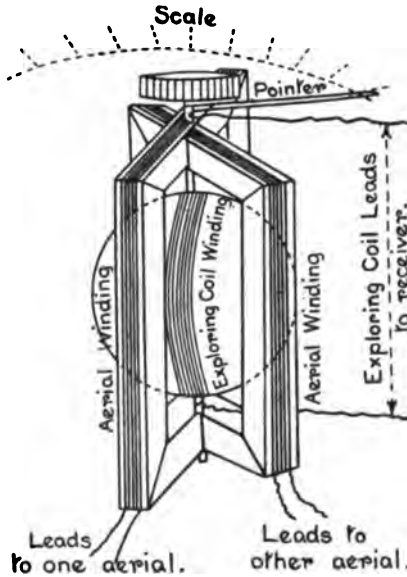


FIG. 111.

number of special apparatuses and additional training of many operators as some considerable skill is necessary in comparing the signal intensity.

To take a specific example the installation of about a dozen radiophare stations around the coast of Great Britain would enable many thousands of vessels fitted with any normal wireless receiver to determine their position, the only additional instrument necessary being a seconds watch. Moreover, the ships would not have to transmit, and, as the radiophares could transmit on some non-commercial wavelength, no additional interference would result.

Such an arrangement entailing no additional apparatus being required by the ship determining its position, is not in favour of companies supplying wireless goniometers, since their apparatus will be unnecessary and therefore not in demand.

It is highly probable, however, that all civilised countries will follow the lead of France and Germany and install "wireless lighthouses" which will, like true lighthouses, continually radiate upon wavelengths, which avoid interference with the commercial and naval wavelengths.

2. On board ships whilst an aerial fore and aft can be easily obtained between the truck of each mast, to obtain an aerial abeam is a more difficult matter, since it interferes with the working of the ship's winches, etc., and even when obtained it is only of small dimensions and natural wavelength.

The radiophare method requiring no special aerial on board a vessel is therefore advantageous.

3. Even when an aerial abeam can be obtained, it is restricted in size, and therefore for efficiency only a small wavelength can be used. Such small wavelength energy easily undergoes reflection from the steel hull of the vessel, etc., and artificial increase of wavelength, by insertion of inductance, lowers the transmission and reception efficiency. Errors of measurement therefore arise, and necessitate the special calibration of each apparatus for each ship, not only on installation, but from time to time. The errors even then vary with the relative position of masses of metal, such as winches, when movement of these occur.

The radiophare method, since the transmitting apparatus is entirely on shore, can select without loss of efficiency long wavelengths which are not nearly so greatly reflected.

4. There is doubtless no English engineer who has so great an experience of the goniometer method than Round of the Marconi Company.

With the most recent valve apparatus of that company, he recently states that by the use of this apparatus, errors can be reduced to 1° , but that for such accurate location of a distant

transmitting station at least three and preferably four direction-finding stations are necessary.¹

The converse of this statement is that if a ship station is to determine its position to 1° , it requires signals from four coast stations. This means special signals between the single ship station and the coast stations, and consequent further disturbance of the ether and jamming to the detriment of other wireless stations.

Of course a ship station might use signals from other stations engaged in ordinary traffic, but then it is dependent upon transmission not under its control, and if the call-signal is not plainly given such transmission is useless, and in any case irregular, and necessitates waiting on the part of the ship station.

5. The radiophare method requires no special manipulative skill on the part of the ship's operator, and very little on the part of the land station operator, who is, however, usually a more skilled man.

6. With the radiogoniometer method only one ship can obtain its position from a number of land stations during the same period, whilst with the radiophare any vessel can do so.

7. In warfare the radiophare method does not call for any transmission on the part of the distant vessel, whilst with the goniometer, transmission must take place from the shore stations to the ship and vice versa, which enables its position to be located by its adversaries, also the shore stations must inter-communicate. It is stated that after our Mediterranean stations had made observations upon a German submarine's signals, and communicated the results to a central station, the German commander sent a message thanking them for their assistance in determining his unknown position. Such an eventuality is overcome by use of land wires if available, but even then much time must elapse before the results are in the hands of the central station.

8. An advantage of the goniometer is that it is rendered independent of special signals from shore stations, assuming it is upon a place on the high seas where known stations can frequently be heard. As without doubt all civilised nations will fit either special wavelength radiophares around their coasts, or equip a number of existing stations with the slight additional apparatus, this advantage in the future will become largely non-existent.

¹ Round, "Journal Institute Electrical Engineers," p. 238, Vol. LVIII, March 1920.

Further Developments of Goniometer Method.—In 1912 the Marconi Company acquired the patent rights of Bellini and Tosti, and the services of M. Bellini.

They appear, however, to have also utilised the services of one of their own employés, Prince, since in the same year we find a patent taken out for a modified Bellini-Tosti arrangement by Marconi Company and Prince.

This modification consisted in that instead of comparing the intensities of signals in the aerial coils by means of an exploring coil, a switch was used which put each coil in turn in a detector circuit, and intensities of signals were measured in the normal way by inserting a variable but known resistance in one circuit until intensities in both circuits were equal.

This would, however, appear to be less rapid in operation than is the case of the original search coil method, and was doubtless found so in practice, since their other employé, Round, when engaged upon work for the War Office, reverted to the original Bellini-Tosti arrangement.

On the subsequent development of more sensitive valve receivers, Round, amongst others, carried out the obvious adaptation of this receiver, for work with the Bellini-Tosti instrument.

Such an adoption has been somewhat boomed as a new instrument. An illustration of the goniometer used with such valve receivers appears in the "Electrician" of 8th August, 1919, as "The Marconi Direction-Finder," concerning which Bellini, whose relations with this company would appear not to be still friendly, and also Artom, both wrote claiming that the new instrument was the same as their goniometer, a statement to which the Editor of the "Electrician" concurs in his issue of 29th August, 1919.

It is interesting to note that, since Artom's claim to be the originator of the Bellini-Tosti goniometer has been upheld by the Italian Courts, and Bellini has published a disclaimer in the "Electrician" to his previous claims, unless the Marconi Company should repurchase the patent rights from Artom, they will possibly be unable to use the goniometer.

Bellini has devised a new form of goniometer in which, instead of employing magnetic coupling of the aerials to the search coil, he employs static condenser coupling. His paper is interesting, and will be found in the "Electrician" of 12th September, 1919.

Perhaps the most interesting new goniometer development is that due to Robinson of the Royal Air Force, which utilises his method.

Little has been published regarding his apparatus, but it would appear from the "Electrician" of 10th October, 1919, that two frame aerials are employed, one fixed across the span of the wings of an aeroplane, and one at right angles to this around the fuselage.

If now the machine is in the "nose on" position to a transmitting station, the aerial around the fuselage will receive maximum signals and that around the wings, theoretically no signals. If a switch is utilised to connect both aerials in series upon wish, no increase in signal strength should occur when the aeroplane is in the "nose on" position, but in all other positions variation of signal strength will result.

The observer in the aeroplane can hence determine his position without making any quantitative measurements except aurally (an advantage over the rotating coil method), and can head his aeroplane to any aerodrome sending signals, without the use of any other apparatus. This method of navigation has been used to guide aeroplanes, unequipped with magnetic compasses, over great distances, as from England to Paris.

Round, in the paper already mentioned, has attempted to prove his own, and Prince's patents cover this simple method used for a particular purpose.

The essential difference is that whereas Prince utilises two circuits in parallel and a switch, for comparison of the circuits one after the other, Robinson uses a special case of the more general one and his apparatus must essentially have the two aerial circuits in series. As Robinson so aptly states, the Prince method may be compared to the use of a Nicol prism to measure optical rotation of two media by their insertion in a polarimeter one after the other, whilst his method is analogous to the use of the more recent half-shade polarimeter, in which one comparative measurement only is necessary.

One result of the adoption of the valve to direction-finding work was with increased sensitiveness the aerials could be much smaller for equal intensities of signals. This has led to a reversion to the original swinging aerial used by de Forest and others, but with the advantage that the swinging aerial can now be a small square frame of about 2 feet side, mounted on bearings so that it can be as easily and quickly rotated as the Bellini-Tosti search coil.

Like the Bellini instrument this does not get over reflection difficulties from masses of metal, but it gives a very convenient portable form of apparatus which can be mounted upon a

motor car and quickly moved about, whereas with the Bellini instrument time was required to erect the aerials, which had to be actually surveyed to overcome errors incurred by the two aerials not being exactly at right angles.

Such forms of portable rotating coil aerial direction-finders were, on the cessation of hostilities, just coming into use to rapidly determine the location of enemy observation aeroplanes and balloons which were transmitting observations to artillery.

In such work the French Telegraph Corps carried out much important experimental work, particularly as regards the effects of surroundings upon the accuracy of results. They used the hard French valve whilst the British stations throughout the war used the soft round valve of the Marconi Company. One reads with amazement Round's statement that he was "entirely unacquainted with the French work" when it is recollected he had considerable influence regarding the installation of British stations. Such an ignorance is to be deplored as against the country's interest.

The Accuracy of Directional Observations.—In no other field of wireless telegraphy have statements, regarding accuracy, been made on less valid grounds. According to Addey an accuracy to within an angle of 2° can be obtained. Stanley claims an accuracy of $.5^\circ$, whilst Round, who has undoubtedly more practical experience, claims an accuracy of only 1° , and says for accurate work at least three and preferably four stations must make simultaneous observations.

In the Army wireless service during the war, the whole business of direction-finding was veiled in secrecy, and those in charge of such stations carried the accuracy to impossible limits on little or no grounds.

The author had not only the opportunity of seeing an officer trained specially for this work make observations, but was also able to do so himself on the very latest type of Marconi manufactured instrument, which, as already mentioned, used the Bellini apparatus in connection with a very elaborately and well-designed valve receiver which, however, unfortunately still used a soft valve instead of a hard and stable one of the French type.

It was claimed by the officer in charge of this station, whose general knowledge was, however, not very deep, that a transmitting station could be tracked down to a particular house, instead of a particular village as the author has grounds to believe is the actual case.

From watching the officer in charge making observations and by doing so himself, the author can positively state from experi-

ence founded upon, not only wireless direction-finders and other wireless apparatus, but on the constant use of much more sensitive scientific apparatus, that the value of personal error was so great that assertions such as the above are entirely unfounded.

Furthermore, since this type of apparatus embodied no new secret principles, and similar and certainly as efficient apparatus was available to the Germans, the author was able to test his conclusion by the following actual experiments:—

At Noyelles village, near Loos, in 1916, then about 1600 yards from the front line, the author had erected a wireless station, controlling his trench installations in the actual front line trenches. This station had an aerial erected between two specially planted telegraph poles taken from the destroyed French permanent lines.

The station was located by the Germans, doubtless by means of first a goniometer and then balloon observation, and for several days it was heavily shelled. As the pack-set station used was merely in an unprotected cellar, on registering a direct hit upon the house, by which fortunately neither the author, his men, or apparatus in the house at the time was injured, the position became untenable, and the author caused the apparatus to be immediately removed to a house about 150 yards away, where a less conspicuous aerial had been erected between two houses.

After destruction of the first house, and doubtless consequent notification of a direct hit by an observation balloon, no further shelling occurred, until in about twenty minutes, when work was reopened from the new location, shelling was recommenced, not at the new situation but at the *old* one. For days the author and his men could by mere transmission amuse themselves by drawing fire at will upon the old location, but the new location was never directly shelled, whereas it is evident that if direction-finding had been brought to the perfection alleged, fire would have been directed to the new location.

The author would go further than stating that within 150 yards a sending station cannot be exactly located by mentioning a further instance.

Among many forward trench installations he had one which, by actual visual observation of repeated aerial erection after destruction by shells, was located exactly by the enemy, since it was only about 300 yards from them. The enemy had also noticed that destruction of the aerial coincided with the temporary cessation of its wireless call-signals. The author caused another station about a mile away to transmit this particular station's

call, and not the actual sending station but the already located one was then shelled, a circumstance repeated over several days, giving ample time for the enemy to locate the new station had direction-finding been sufficiently sensitive.

Some of the claims for direction-finder accuracy are therefore very excessive.

The method was, however, of great use to us during the war, since we were able to locate submarines and to follow the path of Zeppelins, which were guided by wireless during their raids upon England.

For interception purposes a series of direction-finding stations were installed along the east coast of England and Scotland, and a similar chain for directional purposes were installed by the Germans along their coast, which, however, fortunately suffered from forming a bad base-line for their measurements.

When in 1917 five Zeppelins, after dropping bombs on London, drifted over to France and were destroyed, it was commonly stated that the "electrical storm," which the Press stated upset their instruments, was really due to the transmission of false messages and jamming of the true signals by a number of Quenched Musical-spark stations, which the army had at this period extensively adopted.

Previous to the erection of the above-mentioned British interception stations it was, however, perfectly possible, by noticing the continued recurrence of certain signals over a previous period of several hours, to predict that a Zeppelin raid would shortly occur, and even if this method did not give the exact location of these aircraft, it should have been sufficient to permit adequate defensive measures to be carried out.

Some Practical Aspects of Directional Working.—For stations of the Bellini type the signal strength might theoretically be increased by using more than one turn of conductor in the aerial. In practice, however, it is found that in stormy weather relative movement of the turns cause errors due to variation of mutual inductance, and also a much larger capacity aerial is obtained, so that a larger and hence less delicate condenser must be used for tuning purposes. The latter objection also applies to the use of too large an aerial frame. If, however, the aerial frame is made too small the lead-in wires are relatively large in comparison to the frame wires and are therefore liable to introduce errors.

With the small rigid frame portable type of station multiple turns are of advantage since their capacity is much less and

relative movement can be made impossible, so that variation of inductance does not result.

An interesting error, which has been called for no apparent reason "vertical," is also observed when a valve receiver is used.

Since the leads from the secondary exploring coil are, as usual, taken to the battery and grid of the valve, unless the capacity to earth via the grid is the same as via the battery, equilibrium is upset and results in a small error shown by the two minima or maxima positions of signals not being exactly opposite, i.e. separated by 180° .

The error is more interesting than important, but can be easily overcome by inserting a suitable small condenser between grid and earth to restore the balance.

In direction-finding work, control readings from stations of known location demonstrate many errors, some of which are analogous to the ordinary transmission effects. The chief of these are:—

1. *Night Effect*.—Readings are not so accurate at night since sharp readings of the minima signals cannot be obtained.

2. With those continuous wave stations where the aerial continually radiates and Morse signals are sent by a change of wavelength, it is very remarkable that the direction readings of the Morse signals and "spacing" signals (i.e. non-useful intervals between the signals) may give a difference in direction for signalling and spacing waves of the same station which Round states may be as much as 30° .

3. The readings of two stations situated at the same spot, but transmitting on different types of aerial, may show a very wide deviation.

4. As in general work, refraction occurs over land and sea which changes the general wave front direction and introduces errors, especially at night.

5. Reflection occurs, so that direction-finding stations nearer than a distance 2λ to high cliffs, woods, etc.; are quite unreliable, both by day and night.

6. The position of a station varies throughout the day, and great variation occurs at dawn and sunset, doubtless due to the refraction of waves at the part of the range where such an event is taking place. This may give rise to errors as great as 90° .

7. When the direction-finder is used to determine the position of aircraft, errors arise since the aerial trailing out behind does not emit waves having the electro-static field more or less vertical and the magnetic field more or less horizontal. Instead these

fields are inclined to these directions according to the slant of the aerial, which depends upon the speed and direction of the airship. As, however, the goniometer aerial frames used are perpendicular, the portion of the wave front which strikes each is dependent on the condition of the incident wave front, and readings are therefore very unreliable.

The only satisfactory method is when the aeroplane is directly "end-on" or directly reversed to this direction, a position which Robinson utilises in his method already described.

If the aeroplane changes its direction, so that instead of flying more or less towards the receiving station, it flies in the directly opposite direction, these errors are reversed upon the goniometer.

8. When other stations are jamming the aerial currents are the total of all received waves, and therefore readings not being due entirely to the station whose position is desired, errors are introduced to a greater or less degree depending upon the extent of jamming. Ditcham has found, however, that, unless the jamming is intense, by variation of the filament current of the valve, other stations can be eliminated, i.e. there will be one point of the filament current where the desired station only is heard.

All the above effects make it evident that an error of only 1° is a very favourable result in direction-finding work.

One interesting effect, important in the future of meteorological work, is that by the direction-finder, observations on atmospheric, and the course and velocity of electrical storms, can be carried out.

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CHAPTER IX.

WIRELESS TELEGRAPHY UPON SHIPS.

By far the most important use of wireless telegraphy up to the present day has been for the purposes of intercommunication between ships and the shore. There are, according to the Official List of Radio-telegraphic Stations published at Berne (1918), no less than 802 land stations, and the majority of these stations are established along all the trade routes for the purpose of communicating with ships at sea. Those familiar with wireless operators' logs will agree that it is nowadays a very rare occurrence for a vessel to be out of touch with other vessels or the land for the space of a day, even when upon very unfrequented routes.

At the present day there are very few passenger vessels which are not fitted with wireless apparatus, and most of the cargo vessels find it sufficiently useful to justify the initial expense.

The chief advantages obtained by ships so fitted are that they can receive from other ships and coast stations information as to the approach of storms, fogs, icebergs, etc., which are of great use for navigational purposes.

In the event of an accident occurring, the vessel is able to send distress calls for help over many hundred miles and summon other vessels to its assistance. Should the accident not warrant this, information may be sent to the shore, either directly or by retransmission, to allay fear as to the safety of the passengers and crew and to prevent financial losses owing to the rise of insurance rates.

Many such occasions have occurred within the past few years, and have been greatly boomed by the Press and by wireless companies. The advantages are, however, so evident that there exists at the present moment in various countries, regulations making equipment compulsory upon most passenger vessels, and in February, 1914, at the International Committee upon Safety

of Life at Sea, held in London, resolutions were passed recommending all the Governments concerned, which included every civilised nation, to make its installation compulsory upon all vessels carrying over fifty passengers and voyaging further than 500 miles. Present British regulations make wireless compulsory on all passenger vessels and all cargo vessels over 1600 tons.

From a merely commercial point of view many advantages are obtained with wireless telegraphy: for example, a vessel can obtain without alteration of its course and consequent loss of time and fuel expenses, information as to whether any freight or passengers are to be obtained at particular ports. Information can also be sent to vessels instructing them to proceed to a port where the best prices can be obtained for cargoes such as wheat, oil, etc. Arrangements can also be previously sent from the ship to port authorities to arrange for tugs, labour, and lighterage, so that these are ready directly the vessel enters port, with consequent saving of time and saving of dock dues.

As an aid to navigation many coast stations transmit time signals at certain hours by means of which the commanders of ships can calibrate their chronometers. The most important stations rendering this service are:—

Country.	Station.	Time of Transmission.	Wavelength.
France	Paris	9.45 a.m. and 11.30 p.m. (Greenwich time)	2500 m.
Germany	Nordeich	Noon and 10 p.m. (Greenwich time)	1650 m.
United States	Arlington	Noon and 10 p.m. (75° West of Greenwich)	2500 m.
	Boston	} Noon (75° West of Greenwich)	1000 m.
	Charlestown		
	Key West		
	New Orleans		
	Newport		
	New York		
	Norfolk	} Noon (120° West of Greenwich)	1000 m.
	Eureka		
	Mare Island		
	North Head		
	San Diego		
	Tatoosh		
Japan	Choshi	9 a.m. and 4 p.m. (135° East of Greenwich)	600 m.
China	Tsingtau	Noon and 8 p.m. (120° East of Greenwich)	1250 m.
Mexico	Campeche	} Midnight (Time of the meridian of Tacubaya)	—
	Guaymas		
	Mazatlan		
	Payo Obispo		
	Vera Cruz		

Other stations than the above transmit weather reports, either at certain fixed hours, or at certain fees upon request.

Many of the largest ships receive news messages which are published on board for the benefit of the passengers, whose preference for ships so fitted on account of safety and convenience is evident.

Perhaps an unusual but interesting use of wireless telegraphy at sea occurred in 1914, when the third officer of the "Brandenburg" was seriously injured, and an intricate operation was urgently required, concerning which a consultation was held, via wireless, by the doctors of the "Brandenburg" and "Bosnia".

It was at one time a frequent occurrence for chess matches to be played by wireless by ships at sea. Such an entirely unnecessary use of wireless is not, however, to be desired, as it is likely to cause disturbance to the reception of more important messages, such as distress calls. In this respect wireless press messages are not of absolute advantage, since in the ill-fated "Titanic" disaster subsequent inquiry showed delay in other vessels going to its rescue were due partly to the mishap occurring when the majority of operators were listening in on a non-commercial wavelength for the Cape Cod press, partly by ships given in the official list as "continuous service," having only one operator to provide such twenty-four hours' service (for example, the "Californian" was only eighteen miles distant from the ill-fated ship but did not receive its distress signal since the operator had gone to bed), partly due to the absence of an emergency installation on the "Titanic," then recently fitted, and partly due to the absence of knowledge on the part of the operator, that for many years the distress call had been changed from "C.Q.D." to "S.O.S."

In time of war information may be sent by wireless to mercantile vessels permitting them to avoid capture. On the outbreak of war in 1914, all German vessels received a code message to this effect from German land stations, and instructing them to proceed to neutral ports. Whilst this fact was made much of by a certain section of our own Press, it would undoubtedly have been more to our advantage had our own vessels been equally prepared in this respect.

General Features of Ship Installations.—Upon the majority of vessels having an electric lighting or other electrical installation the requisite alternating energy is obtained from the ship's mains by means of a DC/AC Converter, which on the Marconi system is a rotary machine and on the Quenched-Spark system a

motor generator, the direct current side taking 60, 110, or 220 volts and the alternator delivering electrical energy of 500 cycles at 220 volts.

Recent practice shows it more advantageous, at least with the smaller installations, to insert a buffer accumulator battery between the machine and the ship's mains, so that the motor generator is really driven from the battery. This has the advantage of giving a more regular running of the machine, since the variations of the supply are eliminated. Also, as with such a buffer battery a separate battery for emergency work is not required, this ensures that this battery is always attended to and not neglected until some case of urgency occurs, when in such a case, the normal full power transmitter is available and not merely a smaller power emergency induction-coil transmitter.

For the purpose of adjusting the pitch of the transmitted signals, the frequency of the generator can be varied from about 480 to 650 cycles per second. An adjustable resistance serves to regulate the excitation of the motor, and thus to vary its speed and the spark frequency in the transmitter. By this means the tone of the transmitted signals can be adjusted until it is a pure musical note.

Where there is no existing electric installation, as on sailing vessels, a complete power plant, consisting of oil or steam engine, charging dynamo and accumulator battery, must be provided.

The Aerial.—Radiation of the electrical energy is obtained upon vessels by means of an aerial suspended between the masts. This in the majority of cases takes certain conventional forms shown in the following diagrams :—

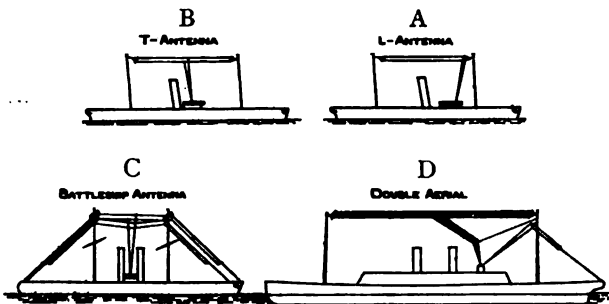


FIG. 112.

Fig. 112 A shows an aerial known because of its shape as an L aerial. This is usually assumed to be somewhat *directive* in

nature, or in other words, when transmitting the waves are projected more favourably in the direction in which the ship is travelling, and a greater range is thus obtained in this direction. The leading-in wires of this arrangement are of necessity somewhat close to the stays of the foremast, and, as they run nearly parallel to them, a loss of energy occurs, unless the stays in question have insulators inserted in them. The exact arrangement of the down leads in this case is decided upon by an engineer on the spot who is able to see exactly how the stays are arranged and ascertain the most convenient and efficient method of "staying off" these leads. This type of aerial is thus somewhat more inconvenient to erect.

The "L" aerial, however, gives an aerial circuit of greater electrical length, and thus less artificial lengthening coils are required in the cabin for producing the longer wavelengths. For this reason this arrangement is often adopted for torpedo boats and destroyers where long wavelengths are always required and only a small aerial can be erected.

The arrangement of the aerial shown in Fig. 112 B, known as a "T" aerial, has the advantage of having an equal radiative power both fore and aft, but in this case the electrical length of the aerial is not so great and the natural wavelength somewhat shorter. The down leads are, however, much less liable to lose energy through their proximity to metal work provided they can be kept at least 7 or 8 ft. from the funnel. The placing of the wireless cabin on the bridge rather than on the forecastle is usually more convenient owing to its proximity to the navigating officers of the ship.

Fig. 112 C shows a form of extended T aerial much used to obtain long aeriels upon battleships in which the aerial is stayed off to the stem and stern from the masts. By leading in the wires from one of the lowest points an L aerial may be obtained if desired. This arrangement is often adopted upon very small vessels such as submarines.

Fig. 112 D shows a large vessel with two aeriels. Such an arrangement is used when the apparatus is very powerful and works most advantageously upon a long wavelength which is, however, too long for the use of the emergency installation. It has the advantage that if in a storm only one of the masts is carried away, the vessel can still use its emergency transmitter.

The number of wires between the masts is usually two, or four, and rarely exceeds six.

The wires are kept apart by means of hollow iron or wood

stretching bars each about 12 ft. long known as "spreaders" which are shown for two and four wire aerials in Fig. 113. Insulation is obtained by strings of "egg" strain-insulators either placed between the masts and spreader or between the spreaders. Often hemp or catgut ropes covered with rubber and about 2 to 3 ft. long are used for insulation purposes.

The hemp ropes supporting the aerial pass over pulleys at the truck of the masts in order that it may be lowered periodically

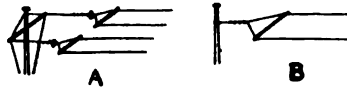


FIG. 113.—Aerial spreaders.

for inspection, since the smoke from the funnels causes slow corrosion of the wire. Phosphor bronze (3 mm.) is generally used since it withstands corrosion better than other metallic wires.

The correct method of joining the aerial and lead-in wires is important practically, in order to prevent breakage of the aerial in stormy weather. The horizontal wires are cut at their middle points, and to each cut end an eye is soldered. These are

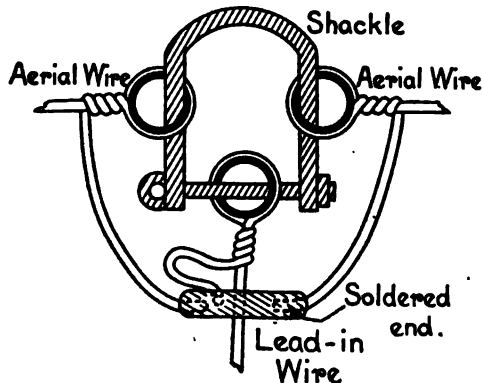


FIG. 114.—Method of connecting lead-in wires.

then held together by a suitable shackle, the pin of which holds an eye soldered upon the leading-in wire (Fig. 114) Upon the leading-in wire is a metallic ball having appropriate drilled holds into which the ends of all three wires are sweated.

Such an arrangement gives good electrical contact, combined with great freedom of movement, without risk of fracture of any of the wires, which would frequently occur if direct connection of leading-in wire and aerial was alone made.

Moreover, no wire-ends are present which would cause a brush discharge and loss of energy during transmission. To prevent such brush discharge, when free ends are necessarily present on any aerial or other wires, it is the practice to sweat small metallic balls.

For most efficient radiation the distance apart of the masts should be at least 1.6 times the height of the aerial from the water line, and all parallel stays of the rigging should be insulated. The down leads should be kept as far as possible away from the funnel and masts, and the "jumper" stay between the masts should be removed, or insulated if this is not practicable.

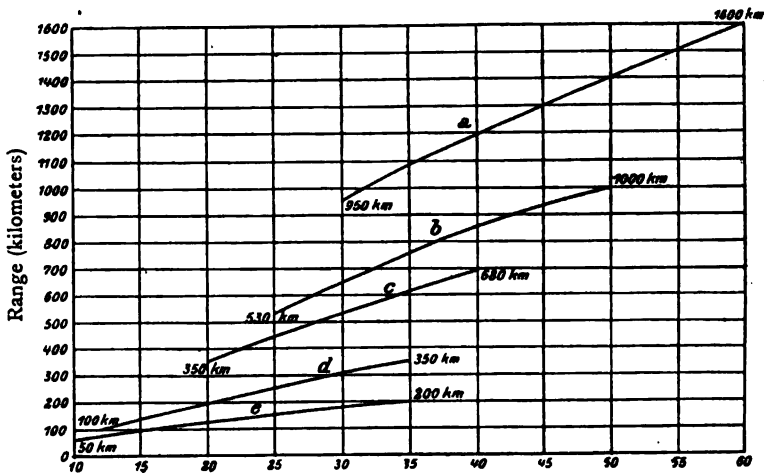


FIG. 115.—Height of masts (meters).

The range obtained is dependent upon the height of the masts from the water line, typical variations being shown by Fig. 115.

The range also differs for day and night, the latter being usually approximately twice the day range, as seen in Fig. 116.

The aerial is led into the cabin by means of a petticoat leading-in insulator described in Chapter III., and often, a trunk is placed up to about 9 ft. from the deck, to prevent anybody touching it and so being injured by shock.

A typical arrangement of a wireless cabin is shown in Fig. 117. The transmitters, receivers, and transformers are placed upon a table against the wall so that the operator can either transmit or receive without moving from his chair. The motor

generator is placed either beneath this table or on the waterproof box outside the cabin, if the space is small or the noise objectionable.

A switchboard to control the motor generator is placed upon one wall, and beneath this the motor starter and speed regulator and the alternator pressure regulators are placed. Upon the wall above the table is placed the aerial lengthening coil, shortening capacity, choke coil, and aerial ammeter.

Efficient ventilation must be provided to remove the nitric oxides caused by the spark discharge, but with a Quenched-Spark station, unless of very large type, this is unnecessary.

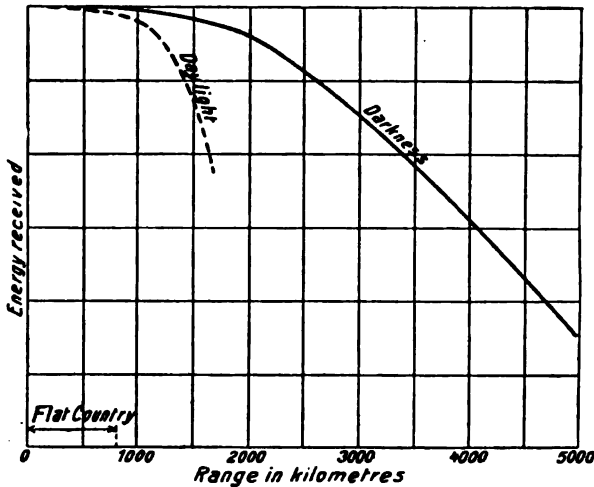


FIG. 116.

With open-spark installations it is necessary to enclose the excitation circuit or at least the spark gap in a double-walled sound-insulated chamber to remove loud, objectionable noises due to the sparking.

This applies also to rotary spark gaps and entails considerable expense, besides taking up a large amount of space. With Quenched-Spark installations practically no noise occurs, so that this silence chamber is not wanted even with stations radiating 15 kw. Upon large vessels, however, the whole cabin is often insulated against *incoming* sounds from the adjoining cabins, etc. A cabin for the operator is situated next to the apparatus cabin, which is usually near to the chart house in order that instructions

can be directly obtained from the bridge. For convenience a telephone or speaking tube connects wireless cabin and bridge.

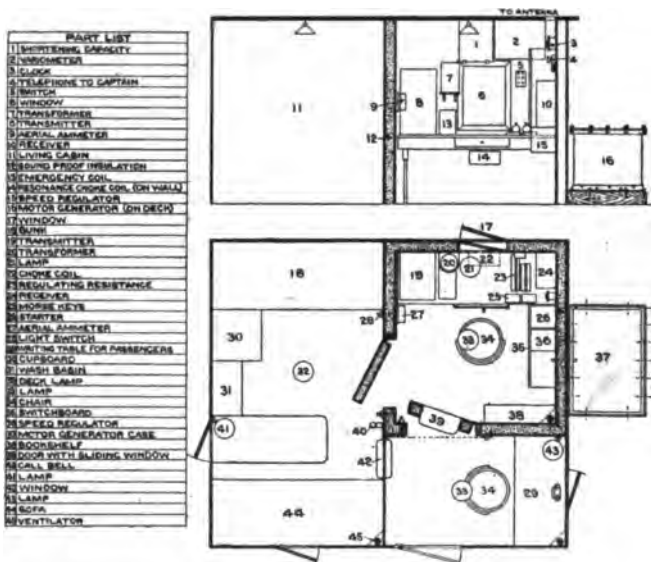


FIG. 117.—General arrangement of a wireless station on board ship.

The normal installations and their normal ranges manufactured by the Telefunken Company are shown in the following tables:—

TELEFUNKEN MARINE STATIONS.

Type of Station.	Energy Radiated.	Wavelength.	Normal Range in Miles.	
			Day.	Night.
Launch . . .	0.5	300, 450, 600	18-30	about double
Yacht . . .	1	300, 450, 600	45-90	60-125
Cargo Vessel . . .	2	300, 450, 600	95-185	135-300
" " . . .	5	" " "	125-250	200-375
Submarine . . .	5	" " "	100-200	2 or 3 fold
Torpedo Boat . . .	1.0	300 to 2000 (continuous)	250	370
Large Cargo . . .	1.0	300, 450, 600	185-320	325-550
Passenger . . .	1.5	300, 600, 900, 1800	375	750
Liner . . .	2.5	300, 600, 900, 1200, 1800	450	800
Cruiser . . .	2.5	600 to 2000 (continuous)	450	800
1st Class Liner . . .	5.0	600, 900, 1200, 1800	750	1500
Battleship . . .	5.0	600 to 2000 (continuous)	750	1500
Vessel of "Imperator" class . . .	7.5	600, 1200, 1800, 2000,	} Depends on circumstances	—
Dreadnought . . .	15.0	600, 1200, 1800, 2000, and 600 to 2000 (continuous)		





FIG. 118.—Launch station.

[To face p. 247.]

Each of the larger powers is manufactured in two types, one working upon a fixed wavelength of 300, 450, and 600 m. for commercial purposes, and the other type, for naval vessels, having a continuously variable wave range between the limits of range, over which it is desired to work.

The ranges, as already mentioned, depend upon the heights of masts and other factors.

Reception of messages for such ranges with each type, with the exception of the launch station, takes place by means of a standard upright Universal Receiver with a wave range from 200-2000 metres and upwards. It should be particularly noted that these ranges are the guaranteed ranges and not those which can usually be regularly obtained. The actual ranges obtained depend largely upon the skill of the operator, and his auditory threshold valve.

For example, to take a Siemens' Quenched-Spark installation on the Tank Storage and Carriage Company's S.S. "Sequoia," for which the range was guaranteed as 200 kilometers by day and 400 kilometers by night, the author in 1914 selected from the operator's log the following typical entries:—

Date.	Time.	Opposing Station.	Range.
Dec. 8th	10 p.m.	Oschishi (Japan)	2100 km.
" 11th	11 p.m.	Honolulu	2600 "
" 13th	1 a.m.	San Francisco	3250 "
" 13th	10:30 p.m.	" "	2800 "

These ranges were obtained with ordinary crystal detectors. Doubtless with modern valve receivers they could be exceeded many times.

The Launch Station.—This station is for use on the smallest types of vessels such as tugs, fishing vessels, and the launches of passenger vessels, designed to take the lifeboats in tow in the event of casualty and then to summon aid from neighbouring steamers.

The complete station is seen in Fig. 118. All the apparatus is mounted upon a board, 1 ft. 8 ins. by 2 ft. 6 ins. which is fixed to a bulkhead.

The station consumes 300 watts from a small battery of accumulators charged from the ship's main or from a small dynamo coupled to an oil engine or belt-driven from the launch engine.

This D.C. current is led to the terminals, 1, through a switch, 2, and fuses, 4, to a small hammer-break coil, 6, which gives the necessary voltage. Interruption of the primary circuit for signalling purposes is carried out by the Morse key, 3, actuating the relay, 7, which alternately puts the receiving or transmitting circuits into use. Regulation of the current supply is obtained by the resistance, 5.

The high-tension current from the induction coil feeds an excitation circuit comprised by an inductance coil, 8, having various tappings, mica condenser, 9, and spark gap, 10, with a regulating inductance, 11. The aerial is led to the insulator, 12, and completed through the lengthening coil, 13, aerial ammeter, 14, and goes to earth at 15.

The receiver is formed of the primary coil, 16, secondary coil, 17, shown removed, tuning condenser, 18, and a detector plugged into sockets, 20. Two pairs of telephones can be used by means of these sockets. Waves from 300 to 600 metres can be received, and transmission takes place upon any wavelength of 300 to 600 metres over a distance of from 18 to 30 miles by day and about double by night.

It is interesting to note that, whilst the "Marconi Year Book" of 1915 describes the installation of the lifeboats of the S.S. "Aquitania" as quite a new departure for that company, the installation just described appears in Messrs. Siemens' "Wireless Telegraphy for Ships," published in 1912.

The Cabinet Station.—This installation is exceedingly neat and compact and is used for vessels, such as yachts, only occasionally requiring to transmit messages.

Such requirements upon small vessels do not permit much space to be devoted to the apparatus, and the whole station is therefore enclosed in a roll front cabinet (Fig. 119) of dimensions 2 ft. 2 ins. × 2 ft. 2 ins. × 4 ft. 6 ins.

The station radiates upwards of 1 kw. and the normal guaranteed ranges are given on p. 246. The author has met with many cases where ranges up to 800 miles have been obtained with this small installation.

D.C. current from the ship mains, or a small dynamo, is led to the switch, 1, through fuses, 2, and regulating resistance, 3, morse key, 4, to the hammer-break coil, 5, which feeds the excitation circuit comprised of three Leyden jars, 6, excitation inductance, 7, and spark gap, 8.

The aerial circuit consists of variometer, 9, leading to the aerial at 10, and going through the hot-wire ammeter, 11, to earth at 12.

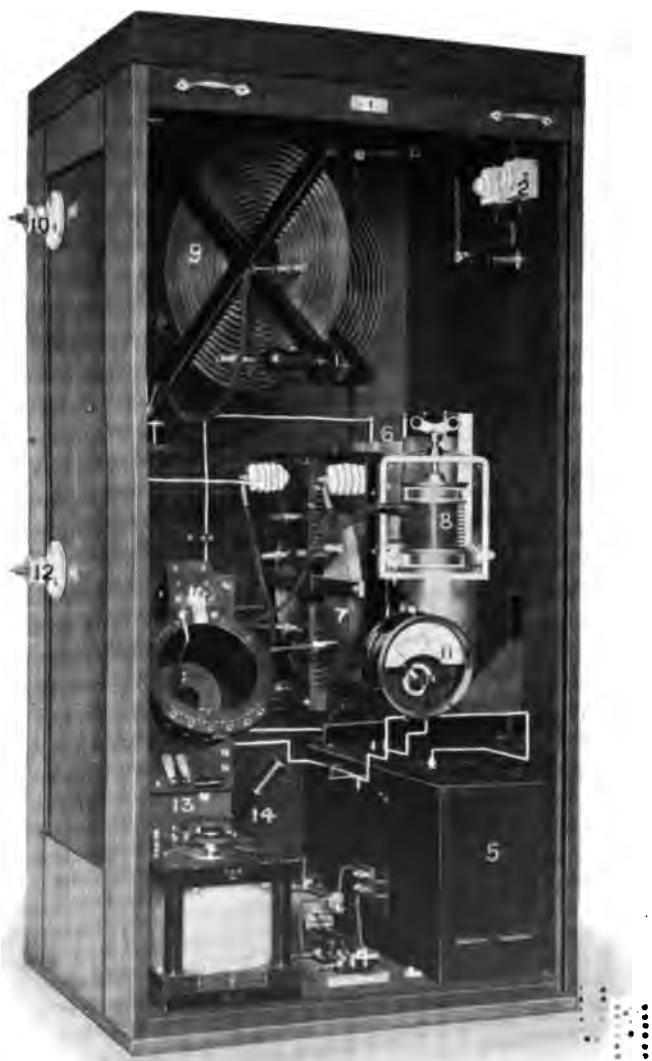


FIG. 119.—Cabinet station.

[To face p. 248.

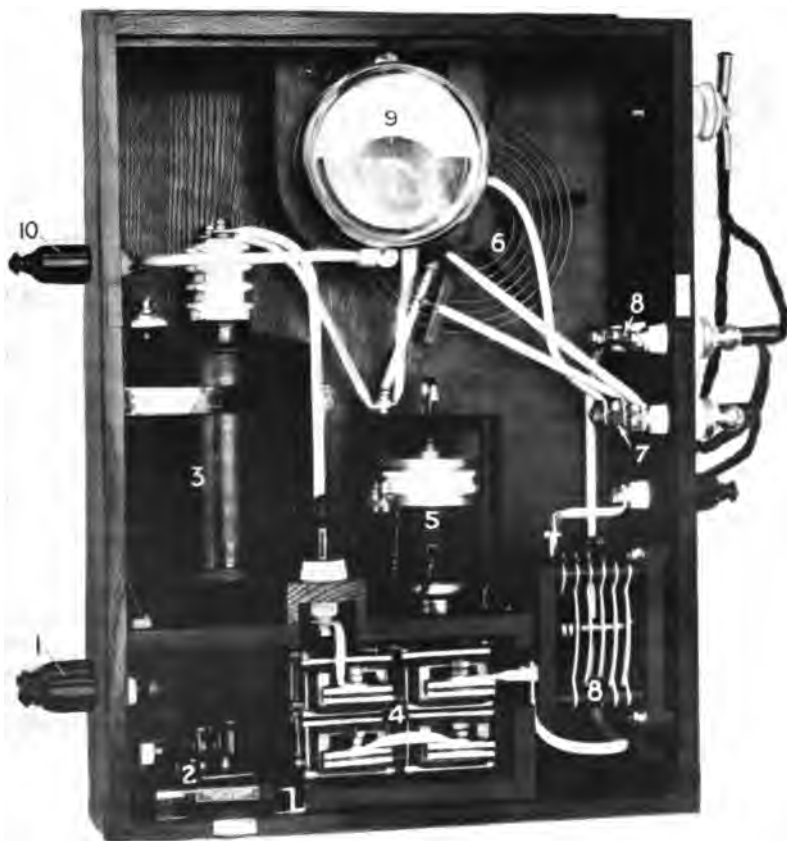


FIG. 120.—Submarine station.

[To face p. 249.

The receiver, 13, is of the Universal type, and change from receiving to transmitting is carried out by the receiver switch, 14.

The Submarine Station.—The erection of a wireless telegraph station on board a submarine presents considerable difficulties as regards the arrangement of the aerial and masts. These are so arranged that they can be removed or lowered upon the boat being immersed and easily re-erected when the vessel comes to the surface. The mast or masts must thus be made telescopic or hinged.

The aerial usually consists of five parallel bronze wires which are insulated and fixed to spreaders on the masts, and can either be arranged in the form of a "T" leading-in at the centre of the vessel, or in the form of an inverted "L" leading-in at one of the ends. If two masts are available, the aerial is stretched between them, with one mast the wires are brought from the top of the mast to the ends of the vessel, and as high and as long an aerial as possible arranged for.

The apparatus is installed either in the navigation tower or in another room as nearly as possible in the middle of the ship. A specially designed watertight porcelain leading-in insulator enables the aerial to be connected to the apparatus (see p. 95). The necessary electrical energy (about 1 kw.) for operation of the station is derived from the accumulator battery on board the vessel. Such accumulators must be specially manufactured, since on the most early equipped submarines severe illness, like anæmia, was caused to the crew during prolonged immersion. This was found to be due to fumes of arsenuretted hydrogen disengaged from arsenic contained in the lead plates and acid of most ordinary commercial accumulators.

The direct-current supplied from the battery is transformed by means of a motor generator to alternating-current of 500 frequency. The motor generator consists of a D.C. shunt-wound motor of about 1½ h.p. direct-coupled with and mounted on the same bedplate as a single-phase 500 cycle generator of about 500 to 700 watts output.

On account of the noise produced within the closed space, the motor generator is installed either in the accumulator room or in a specially built sound-proof box, and is started by means of an automatic starter in the telegraph room.

The essential parts of the telegraphic apparatus are built into two wooden cases which can be installed as most convenient in the telegraph room. In the one case (Fig. 120) is mounted the

key, 2, transformer, 3, and the excitation circuit consisting of paper condensers, 4, spark-gap, 5, primary inductance, 6, and the aerial ammeter, 9, can also be seen in the illustration. The inductance, which is mounted on the back wall of the case, consists of $7\frac{1}{2}$ turns of copper strip. Tappings are taken from three fixed points corresponding to 300, 450, and 600 metre wavelength, to plug sockets, 7, mounted on the side of the case. For obtaining any of these wavelengths on the excitation circuit, it is only necessary to insert the corresponding plug in the suitable plug socket. A small handwheel outside the case governs a variometer, 8, which serves for the exact adjustment of the excitation circuit to the aerial circuit by means of the aerial ammeter.

The second case contains the box-type aerial lengthening coils. At the side of this case are the three plug contacts for connection with the corresponding plugs of the transmitter case. For adjustment of the transmitting apparatus to the correct wavelength, it is only necessary to plug in the correct plugs on the excitation circuit and aerial coil cases, and adjust the variometer in the excitation circuit until the aerial ammeter shows its maximum reading.

The receiver consists of a standard Universal Receiver with contact detector. By means of this instrument a large wave range can be obtained. The apparatus is also adapted for reception of wireless telephony, and with the aid of a buzzer it may also be used for the reception of undamped waves.

Commercial Ship Stations.—These are manufactured in four powers to radiate 0.2, 0.5, 1.0, 1.5 kw. They all work from motor generators of the necessary output at 220 volts, 500 cycles, with a speed regulator to vary the frequency over a range of 30 per cent. either way.

These stations are manufactured in two types known as the "Tropical" and "Box" types.

In the "Tropical" type station, the excitation circuit has a battery of Leyden jars. This form is particularly suitable for use in the tropics as there is practically no woodwork used in its design.

In the "Box" form, the primary inductance, spark gap, hot-wire ammeter, and adjusting inductance are combined in one wooden case. Instead of Leyden jars, an oil condenser in a sheet-iron case is used. This form of apparatus takes up slightly less space, and all the wood used in its design is well-seasoned teak. The power and efficiency of the station is the same in either form.

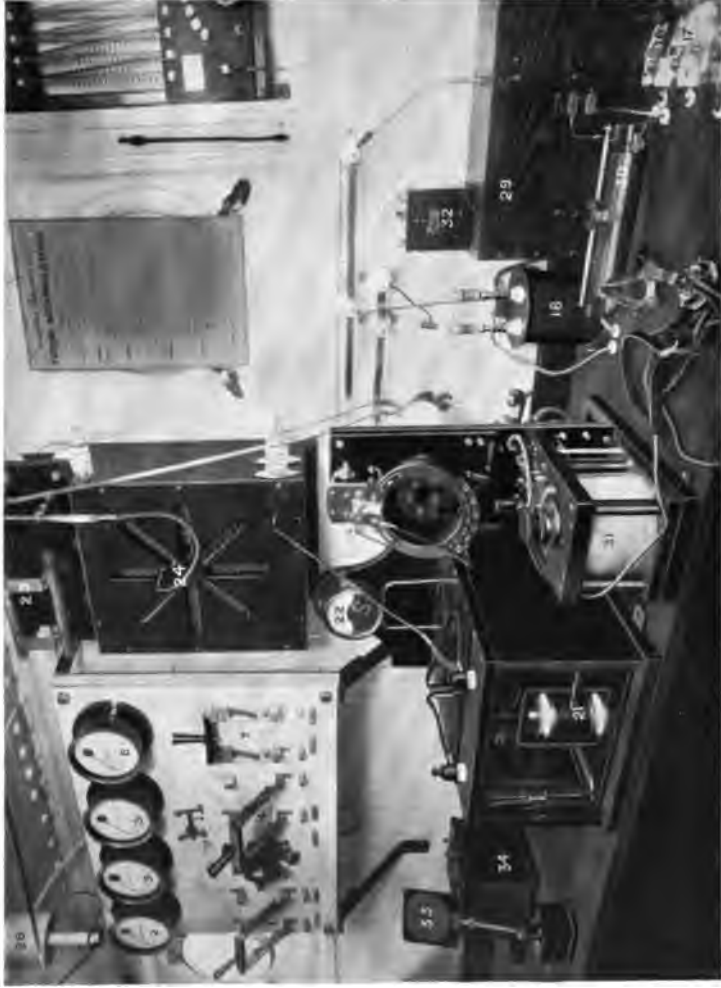


FIG. 121.—Box type ship station (A. Holt & Co.).

[To face p. 250.]



FIG. 123 a—Variometer.

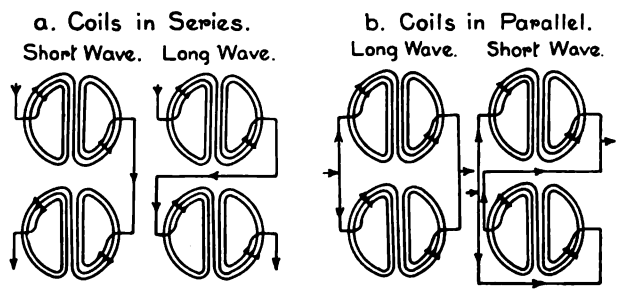


FIG. 123 b.

[To face p. 251.]

A station of the tropical form has been dealt with in detail upon p. 96, and it is only necessary to state that in the 1·5 station, with which ranges up to 2500 miles have been obtained, the excitation circuit is of the heavier type shown in Fig. 29 *a*.

A typical example of the "Box" type is shown in Fig. 121, being a station which was installed on an A. Holt & Co. liner.

The excitation circuit is the same as that dealt with in Chapter III. Above it is placed a box type lengthening coil, 24, and a shortening capacity, 23, for use upon the 300 metre wave. To the left is seen a standard switchboard for the control of the motor generator and to charge the emergency battery for actuating the induction coil, 29, which is regulated by the resistance, 30.

The motor-generator is installed beneath the apparatus table and current from it is stepped up by the transformer, 18.

The remaining apparatus seen is the battery charging resistance, Universal Receiver, 31, aperiodic circuit, 33, buzzer, 32, wavemeter, 34. This illustration should be compared to the "Tropical type" station shown in Fig. 41.

The Torpedo Boat Station (Fig. 122).—Unlike the previous stations, this station being for naval work has a continuous wave range. Paper condensers are also used as these take up less space than Leyden jar or oil condensers, this being an important factor upon very small vessels which, while requiring a long range, have only a limited space available.

To obtain this continuous wave range the inductances are made up differently, so as to be continuously variable. They are seen with graduated scales, the one on the left being the excitation circuit variometer and that at the top being the aerial variometer. These variable inductances, a detached example of which is shown in Fig. 123 *a*, are made up of two circular flat co-axial ebonite plates, one being fixed and the other capable of rotation about its axis. Each plate contains two windings, as indicated in Fig. 123 *b*, and by means of a switch the four coils can be connected in series or in parallel. If the plates are so arranged that the fields of the four coils are added, the inductance is a maximum, and if the movable plate is then rotated through 180° the inductance is a minimum intermediate position giving wavelengths between the extreme values. One complete revolution of 360° and one commutation of the coils from parallel to series by means of the switch seen in front of the coils in Fig 123 *a* gives a variation of 1 to 16.

After being installed the transmitter is calibrated by means of a wavemeter for the particular aerial, and a curve obtained, showing the relation between wavelength and degrees, as read upon the variometer scales. This curve then permits any particular wavelength to be used by setting the variometers at the correct degrees as read from the calibration curves.

The excitation circuit condensers are of the paper type and are placed beneath the spark gap. By means of the switch in front (Fig. 122) they may be put in series or parallel to obtain particular wave ranges.

It should be noticed how extremely small this transmitter is for the corresponding long range of 250 miles by day and 370 miles by night, which may be bridged by this transmitter when radiating 1 kw.

The remaining parts of this station are a set of further aerial lengthening coils if these are necessary, which are mounted upon a bulkhead in the most convenient spot and the usual Universal Receiver.

Large Ship Stations.—There are few cargo vessels able to radiate efficiently more than 1.5 kw., owing to the restrictions placed upon the dimensions of the aerial by the masts.

Upon first-class passenger liners and warships it is possible to install larger stations radiating 2.5 or 5.0 kw. This is about the limit for mercantile vessels, although upon the large German liner, the S.S. "Imperator," a station radiating 7.5 kw. is installed. This station must, however, be regarded as exceptional.

With many warships, where the question of cost and space is not so important, special masts can be built to radiate more than the above amounts of energy, for example, there have been constructed at Siemens' works at Woolwich, five warships' stations radiating 15 kw. To radiate 2.5 kw. the height of the mast should be about 115 ft. high, and ranges of 400 miles by day and 800 miles by night can then be always obtained (except during electrical storms) upon the most advantageous wavelengths. Such a station is normally equipped for radiation upon the 300, 450, 600, and 900 metre wavelengths for commercial work, or with a variable wavelength between the range of 350 to 2000 metres.

The 5 kw. station requires masts 120 to 180 ft. in height and between 200 to 300 ft. apart, with a natural electrical capacity from 1500 to 2000 cm. The fixed wavelengths are usually 300,



FIG. 124.—2.5 T.K. Commercial station.

[See p. 253.]



FIG. 125.—2.5 T.V. Naval station.

[To face p. 253.]

450, 600, 900, and 2000 metres, and a range of 750 miles by day and 1500 miles by night can be safely guaranteed for the most favourable wavelength. With naval stations the wave scale of this type of station is continuous from 350 to 3000 metres.

The fixed wavelength mercantile stations take the form shown in Fig. 124. Alternating 500 period current at 220 volts is transformed by the transformer to 10,000 or 15,000 volts according to the size of station, and feeds an excitation circuit consisting of a 12 or 16 part spark gap, seen to the top right-hand corner, a Leyden jar battery of 48,000 or 72,000 cm. capacity, and an excitation inductance of three flat coils, just visible below the table.

The aerial circuit contains a lengthening coil seen to the left, and goes to earth through the ammeter. This lengthening coil consists of five flat coils of which two are movable and three are fixed, these being arranged symmetrically between each other. The relative position of the two sets of coils can be varied by the handwheel seen in front of the ammeter, for the purpose of tuning the aerial circuit to the excitation circuit. Tappings upon these coils are taken for the various wavelengths by means of sockets upon the front upright. Similar plug socket tappings for the excitation inductance are upon the table above the latter inductance.

A switch puts the transmitter in or out of action by breaking the low-tension alternating current circuit in which is a relay operated by the Morse key for signalling, and a variable resonance choke coil for tuning low and high-tension transformer circuits.

The secondary windings of the transformer are protected by means of two choke coils against breakdown due to high-frequency current surges.

The spark gap is cooled by a ventilating motor, working from off the direct-current supply, which drives air up the chute upon which the aerial ammeter is mounted.

If necessary, lengthening coils or shortening capacities are installed in the aerial in addition to the set of lengthening coils already mentioned.

Fig. 125 shows a naval station of 2.5 T.V. size, with a continuous wave range. The features of this station common to both the commercial and naval stations will be easily recognised.

The essential differences are the variable inductances in the excitation and aerial circuits respectively. The first mentioned is seen to the right, and the second in the centre. They

consist of a set of fixed coils and a set of movable coils moving between the former, and wound in the opposite direction to them. The inductance varies from that due to the odd coil only, when the variometer is in the closed position and the effect of an equal number of coils is mutually cancelled, to that due to practically all the coils when these are in the open position. Upon each variometer a degree scale is provided for calibration and a locking device so that the variometers can be quickly locked in any desired position.

To obtain different overlapping wave ranges a small switch is provided above the excitation inductance which puts the coils in series, parallel, or series-parallel.

The fixed lengthening coils with tappings corresponding to these variations are enclosed in a ventilated iron case, and since an aerial variometer is provided, the coils need not be capable of relative motion.

The latest form of 5 kw. variable transmitter, as manufactured by Messrs. Siemens of Woolwich, is shown in Fig. 126.

Here, the primary variometer is a long helix of nickel-plated copper let into insulating material, which rotates by means of the handle seen in front of the enclosing case B. By rotating this coil the relative position of the contact is varied for tapping off the necessary length of coil to alter the inductance and therefore the wavelength. This contact carries a pointer and a locking handle which may be seen on the top. The pointer works along a scale upon which the wavelengths are marked after calibration.

In this particular station the condensers are of the metal cased, paper type, and these, together with a 15,000 volt transformer and the signalling relay, are installed beneath the table of the transmitter. In the centre of this table is the 18-part spark-gap which is air-cooled in the manner usual for large stations, and in the illustration is hidden by the excitation inductance. Changes of wave range and power transmitted can be brought about, by altering the method of connection of the excitation condensers by the handle at the back of the transmitter. This also automatically works an apparatus, seen above the aerial lengthening coils, which ensures that the aerial circuit is correctly adjusted, since the lead to the aerial from the lengthening coil is only sufficiently long to reach the correct plug socket for the same wavelength, as that for which the excitation circuit has been set.

A small marble switchboard in the front carries the necessary

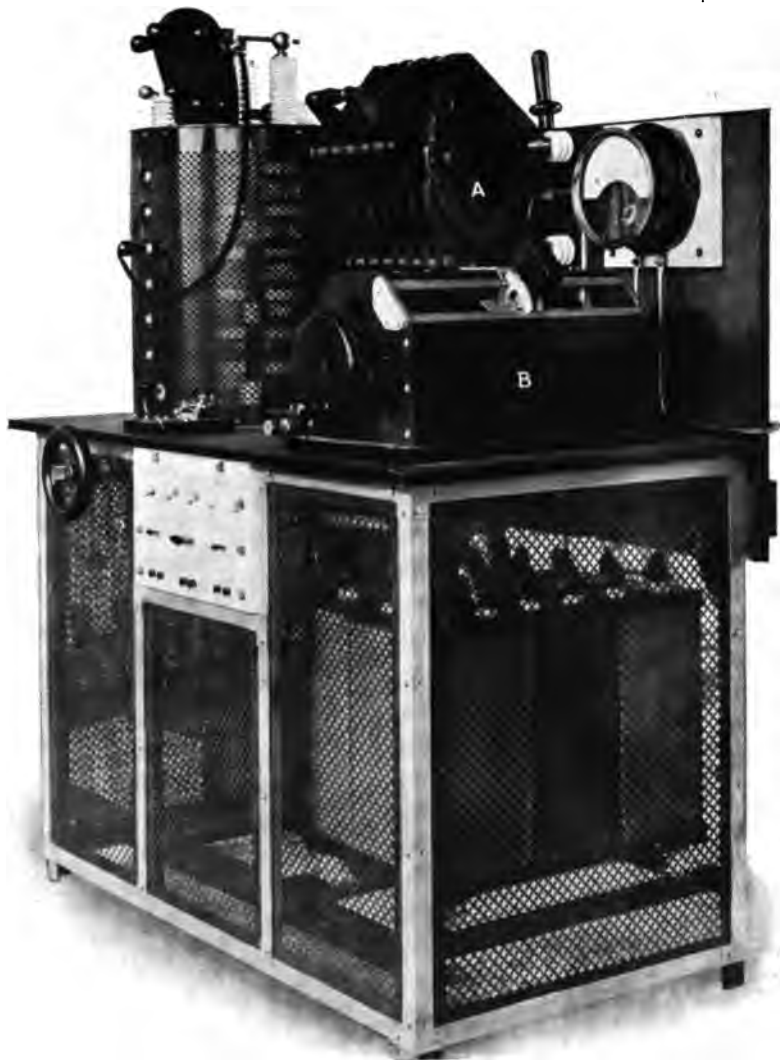
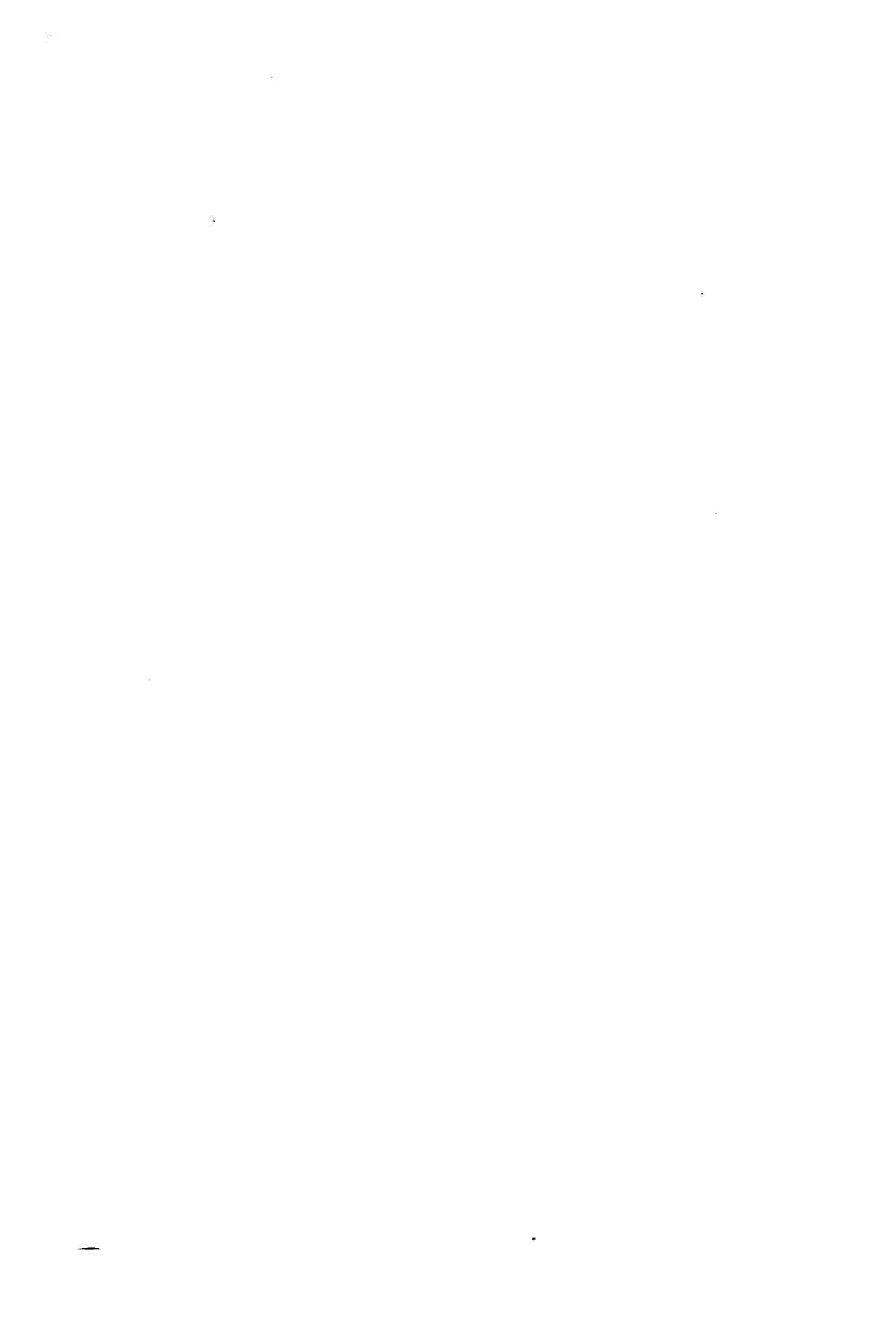


FIG. 126.—Siemens' 5 T.V. Naval wireless station. [To face p. 254.]



fuses and switches for the relay fan-motor in the direct current circuit and main switch in the low-tension alternating current circuit. The motor of the motor-generator is fitted with automatic starting apparatus.

Wireless Station upon the S.S. "Imperator",—A somewhat detailed description of this installation has been inserted, since, whilst of purely German origin, this vessel when built was intended to be the largest and most perfectly equipped mercantile vessel. In common with all other equipment, no expense was spared in the installation of the wireless apparatus, and certainly at the period (and as far as the author is aware, up to the present) no other such elaborate mercantile spark installation existed. It will therefore be of general interest to the British wireless engineer, particularly as this vessel has now come into our own possession. It was in New York when war was declared, and subsequently handed over to the British Government by the U.S.A. Government.

The Telefunken Company installed a still more powerful wireless station upon the later built "Vaterland". This, however, was not a spark transmitter, but a continuous wave transmitter for both telegraphy and telephony. The particular feature of this vessel's installation was that in addition to having a spark installation, it was the first ship to carry a telephony station, worked by a high-frequency machine. Up to this date such machines had been far too complicated to be used on board ship, and the installation had only been rendered possible by the production of the Arco static high-frequency generator. A photograph and details of this installation are given in Chapter XIII., dealing with continuous wave work.

The wireless station erected upon the "Imperator" was built with regard to the following conditions :—

1. The wireless station during its passage from Europe to North America was able to receive at all times press and private telegrams from the land.
2. It was also able to forward telegrams to all vessels within its wireless range.
3. The station was able to work upon the waves of 300 and 600 metres, in addition to the 1800 metre wave with which it was fitted for direct communication with Germany.
4. It was necessary during the receipt of press messages upon the longest wavelength to also be able to receive calls and distress signals at the same time.

5. It was able during the despatch of telegrams to hear distress signals from other ships.

6. In the construction of the emergency transmitter the following points were observed:—

- (a) The station could not be rendered useless should the main aerial fall.
- (b) The station would be able to be used should one of the masts be destroyed by collision or wreck.
- (c) To provide a double reserve of power for the transmitter, so that transmission could take place even when the main engines of the lighting generators were not working, either owing to engine trouble or otherwise.

These requirements had not up to the moment been necessitated for any ship station, so that the wireless station upon the

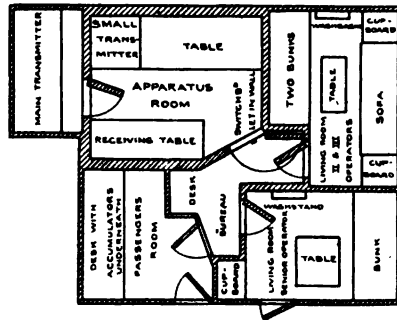


FIG. 127.—Arrangement of "Imperator" station.

"Imperator" can be regarded as a "non plus ultra" in wireless technology and from the point of view of international work.

General Arrangement of Station (Fig. 127).—For the installation of the apparatus and with living and operating rooms, there are five rooms and a recess, which are situated upon the uppermost deck, the so-called "A" deck.

The chief operating room, which has sound-proof walls to prevent *incoming* noise, has a cupboard in which the transmitter of the small station for short range working and the induction coil of the emergency set is installed. Above this cupboard is an ammeter and an aerial variometer for tuning the aerial circuit to the excitation circuit. On a table near the cupboard is placed a wavemeter for use in adjusting of the station, and upon the side wall above the table is a switchboard, with the necessary measuring and indicating apparatus, switches, and fuses.

The starter and speed regulator for the motor-generator are mounted upon the wall beneath the switchboard.

Upon a special bench are two receivers, duplex relays, sound-intensifying apparatus, and three keys for working the three separate stations which are installed. To this bench are brought all leads which enter into the working of the installation, so that the telegraphist from his chair can, without moving, operate all the necessary handwheels and switches during operation. This chair is therefore the centre of the whole installation.

In the recess, to which communication between the main room is made by means of a door, is arranged the large transmitter. Before the apparatus room is an office for the senior telegraphist to receive telegrams, and a passengers' room with a table for writing telegrams. Under a table in the passengers' room is an accumulator battery for the emergency transmitter.

For the three telegraphists there are two living rooms, the first telegraphist having a room for himself, and the second and third telegraphists sharing the other room. The apparatus room and the switchboard room are provided with skylights, through which pass the insulated leads to the aerial.

In order that the noise of the motor-generator will not be objectionable the machines are situated some distance away from the apparatus room. Since the motor-generators for the transmitters require no constant attention, and the regulation of the speed and voltage can be carried out from the telegraphist's seat, there is no objection to their being so situated away from the cabin.

Aerial.—The "Imperator" is the first commercial ship possessing triplicate aerials.

In Fig. 128 is seen the largest aerial which is of "T" form and is led to the operating cabin by down leads just before the middle funnel. It is 64 metres above the water line and consists of four wires each having a length of 170 metres.

In order to obtain the greatest possible distance between the single wires there is at the top of each mast a fixed spreader 5 metres in length, and suspended from each end are two free spreaders each 2.5 metres long, which carry the aerial wires. The total breadth of the largest aerial therefore amounts to $7\frac{1}{2}$ metres. The natural wavelength amounts to about 720 metres and the natural capacity to about 2300 cm.

Besides this large aerial, designed for communication with other large stations upon the 1800 metre wave, for long distance work and the receipt of press messages, the "Imperator" possesses two other aerials, each of which is distinct from the

main aerial. This permits the normal telegraphic work to be carried out with the smaller station or the emergency set during the receipt of press messages upon the large aerial.

The aerials for these smaller stations each consist of one wire which comes from the mast head and is stayed off from the funnel at a distance of 3 metres and then passed to the operating cabin.

This arrangement, in addition to the above advantage, also permits of greater safety to the vessel, since, should the large aerial be destroyed during a storm, there are two reserve aerials present. Also should one of the masts break, the vessel is able to transmit over a considerable distance with the small aerial supported by the mast not carried away.

The great difference in the size of the "Imperator" aerials and that of a vessel of 10,000 tons is realised from Fig. 128.

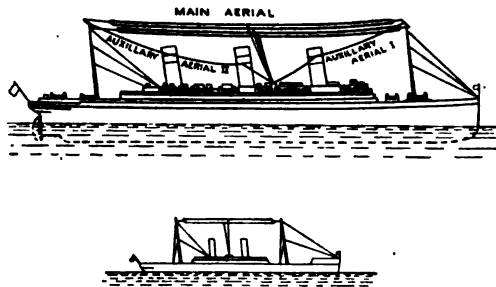


FIG. 128.—Comparison of "Imperator" aerials.

Whereas a vessel of this dimension only possesses one aerial, usually radiating about $1\frac{1}{2}$ kw. of energy, the "Imperator" possesses two aerials for the same power and, in addition, a large aerial which radiates four times this power.

Transmitter.—The transmitting system of the "Imperator" consists of the following:—

- (a) Large transmitter for transmission over 1500 to 3000 kilometres;
- (b) Small transmitter for transmission over 600 to 1200 kilometres;
- (c) Emergency set for transmission over 200 to 400 kilometres;

the two figures given being the ranges for day and night respectively.

The source of current for the large station is a direct-current motor-generator working from the lighting system of the vessel



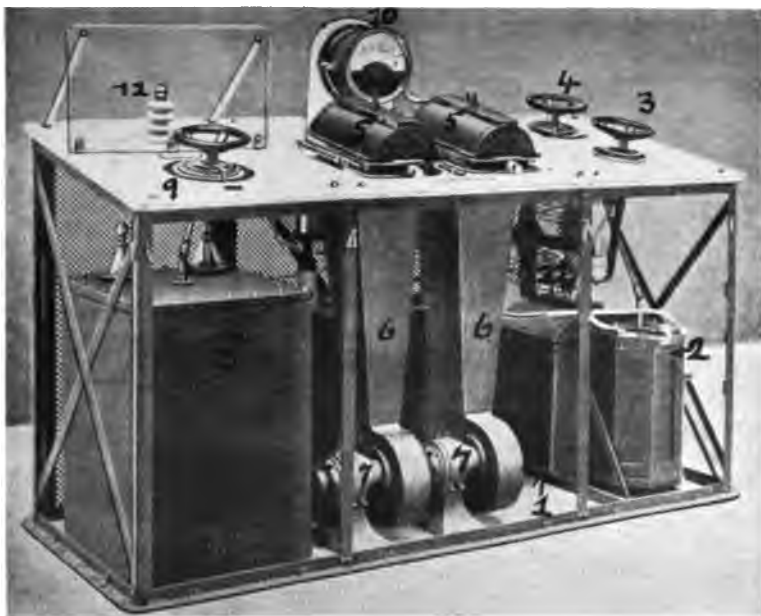


FIG. 129.—7.5 T.K. station on board the "Imperator".
[To face p. 259.]

This motor-generator consists of a D.C. motor of about 18 h.p. and an alternating-current generator of about 10 kw. at 220 volts.

The speed of revolution of the motor-generator is normally 1500 per minute, and the periodicity of the generator 500 per second. In order to obtain the best tone of emitted signal the frequency of this generator can be regulated by means of the speed-regulator between the limits of 480 to 650 cycles per second.

To regulate the excitation of the generator and the number of sparks per second, a sliding resistance is used by means of which the purity of the note of the transmitter can be adjusted.

The alternating current of the generator is transformed from 220 volts to between 10,000 and 12,000 volts by means of an iron-core transformer.

In series with the secondary winding is a secondary choke coil, the windings of which consist of many fixed thinly wired coils. The coil is so connected that it protects the transformer against high-frequency surges and also serves to produce resonance between the transformer and excitation circuit.

The excitation circuit consists of an oil-immersed plate condenser, two 8-part Quenched-Spark Gap and a variable self-inductance coil.

The latter carries plug socket contacts for the various wavelengths. The wave scale of the station is between 600 to 3000 metres, but in practice it works practically exclusively upon the 1800 metre wave. The complete transmitter which was built specially for the "Imperator" is shown in Fig. 129.

All the excitation-circuit apparatus is built within an iron stand, and there may be seen from left to right the oil condenser, 8, and two ventilators, 6, beneath which are motors, 7, driving currents of air to cool the spark gaps, 5, above.

Behind the chutes, 6, is the high-tension transformer, and to the right the excitation self-inductance, 2, and the aerial lengthening coil, 11.

Upon the marble plate at the top are the two spark-gap sets, 5, behind these the aerial ammeter, 10. Three handwheels to be seen serve to tune the transmitter to any particular wavelength, that to the left, 9, adjusts the excitation capacity and the two handwheels to the right, 4 and 3, adjust the coupling and change the wavelength of the excitation circuit.

The small station is a normal 1.5 T.K. station, and is, together with the emergency transmitter, built in a wooden cupboard.

These work separately either off the ship's mains by an enclosed direct-current motor-generator delivering about $2\frac{1}{2}$ kw. alternating current in the first case, and from an accumulator battery in the second case.

To tune the aerial to the necessary wavelength a variable tuning-coil is mounted upon the wall which consists of the usual type of variometer. Beneath the coil is the hot-wire ammeter for this station which serves to control the tuning of the station and shows the value of the aerial current.

As a source of current for the emergency set induction-coil accumulator batteries are used, which can be used in combination either with the main lighting system, or the emergency lighting system of the vessel.

For the emergency transmitter the excitation circuit of the small station is used.

Should the lighting system of the vessel fail for any reason it is only necessary, in order to set the emergency set in action, for the operator to work the necessary switches at the central switch-board of the station.

Receiving System.—The receiving station consists of two separate Universal Receivers, one being for the large aerial and one for the two small aeri-als.

Both receiving circuits can work at the same time, i.e. while the large aerial and its combined receiving apparatus is receiving long wavelength messages, the second receiving apparatus, in combination with the second or the emergency aerial, can receive either emergency signals or telegrams upon the smaller 600 metre wavelength at the same time.

The apparatus effecting this has already been described (Chapter VI.), and it is only necessary to remark that a device is present by means of which the receiving apparatus is automatically switched in as soon as either transmitter stops working.

An automatic blocking device is present by means of which it is impossible to switch in the receivers when transmission is taking place so that no danger to life occurs.

Upon the wish of the Hamburg-American Line the "Imperator" was equipped so that when working with coast stations it is always possible to receive messages from ships at sea.

This requirement is made possible by means of a Duplex Switch. The method of working this arrangement has been described in Chapter VIII. If during transmission when one station is sending, a third station commences working and so interferes with the opposing receiving station, and the original sending

station should not be aware its signals to the opposing station are being jammed, a great loss of time is involved. Such a loss of time is particularly important upon the North-American route, where there are a large number of vessels working upon the same wavelength, so tending to interfere with each other.

Upon the "Imperator" installation by means of the Duplex Relay it is possible, whilst transmitting, to hear signals sent by the opposite station, during the small pauses between the signals being sent by the transmitting station.

This also makes it possible to receive urgent telegrams, for example, distress signals while transmitting, and to exchange service messages dealing with the forwarding of telegrams, curtailment of energy, and change of wavelength.

It is of great importance from the point of view of the economical working of the vessel, since it saves a great loss of the time available for telegraphing a large amount of traffic, besides lightening the work of the telegraphist.

The value of the Double Receiving and Duplex Relay devices has been shown during the first voyage of the ship, as without these devices it would not have been possible to carry out the large amount of telegraphing and press work which took place during this voyage.

The Duplex Relay which has been built upon the vessel is, in spite of its great simplicity of construction, highly reliable chiefly because very sensitive contact detectors can be used in connection with it.

The method of connection of this Duplex Relay is similar to that described upon page 203, the connections to the various circuits being the same, but there is no retarding device, change from receiving to sending being immediate. The apparatus is mounted in a flat position instead of upright and the detectors are mounted as near to the contacts breaking the detector circuit of the receiver as possible, in order that they are not injured by self-inductive effects due to the leads (see Fig. 89).

The connections of the complete station upon the "Imperator" are given in Fig. 130.

Large Station.

1. DC/AC motor-generator and low-tension circuits.
 2. Transformer.
 3. Spark gap.
 4. Excitation capacity.
 5. Excitation self-inductance.
- } Excitation circuit.

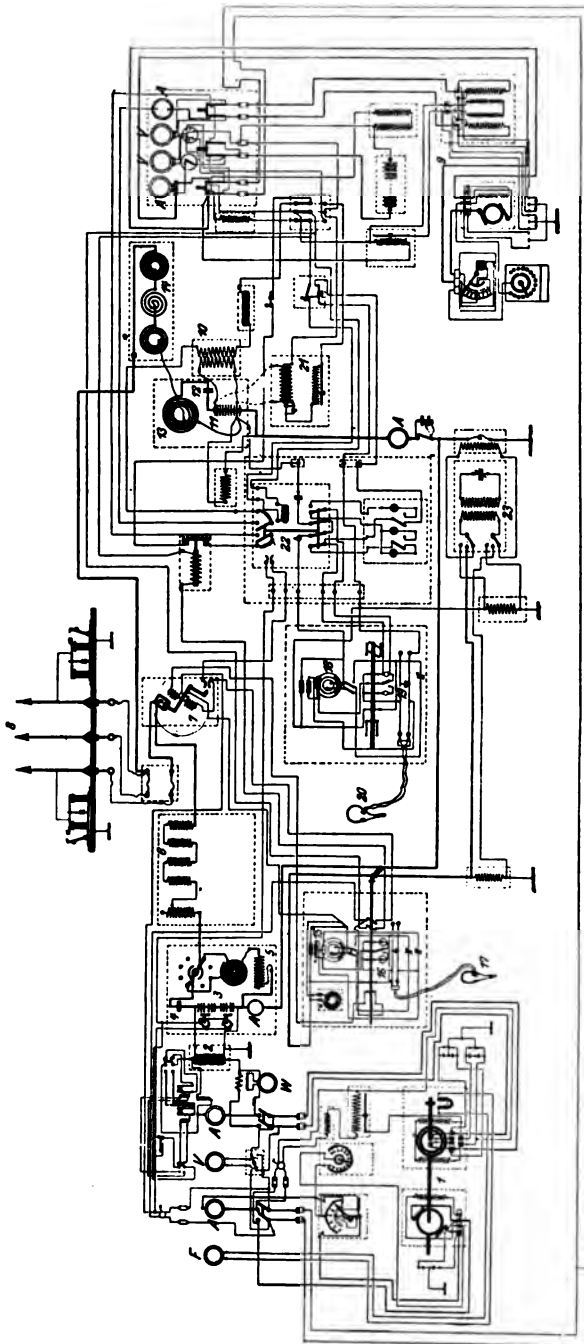


FIG. 130.—Diagram of connections of "Imperator" installation.

6. Aerial lengthening coil.
7. Automatic aerial sending and receiving switch.
8. Aerial lead-in arrangement.

Small Station.

9. DC/AC motor-generator and low-tension circuits.
 10. Transformer.
 11. Spark gap.
 12. Excitation capacity.
 13. Excitation self-inductance.
 14. Aerial lengthening coils.
- } Excitation circuit.

Receiving Arrangement for the Large Station.

15. Receiver.
16. Detectors.
17. Telephones.

Receiving Arrangement for the Small Station.

18. Receiver.
19. Detector.
20. Telephone.

Various.

21. Induction coil for emergency set.
22. Duplex relay device.
23. Wavemeter and testing apparatus.
24. Switch to emergency battery.

The technical features described made it possible for the "Imperator" to carry out an exceedingly great amount of traffic, constituting a World record, which is not likely to be quickly beaten, since the traffic during the first five voyages amounted to 172,000 words, therefore an average of 34,400 words per voyage.

During both day and night the station, which has three operators, is able to send telegrams direct to the land, to other ships, or to send Ocean Letters for transmission by other ships on arrival at port. These may be private telegrams, Ships' Service telegrams, Radio Service telegrams, Navigation Service telegrams, or Time Signals, etc.

Fig. 131 shows the route of the "Imperator," and the mid-day positions are marked. It will be noticed that during the whole

voyage the ship was in communication with land, either in one direction or the other, so that despatches could be directly sent to or received from the land. It was also in communication with a large number of other vessels, so that messages could be sent for further transmission by post when these vessels touched at a port.

During the first day the ship worked with Nordeich and Sheveningen in Holland, on the second day it worked with the English stations of Bolt-Head and the Lizard as well as with Nordeich. During the third day it still worked with Nordeich and also with the other stations during the night between the third and fourth day.

Crookhaven upon the Irish coast, and Ushant, near Brest, were also still within range upon the third day.

After the night of the third and fourth day the connection with Nordeich was broken, but by this time communication with

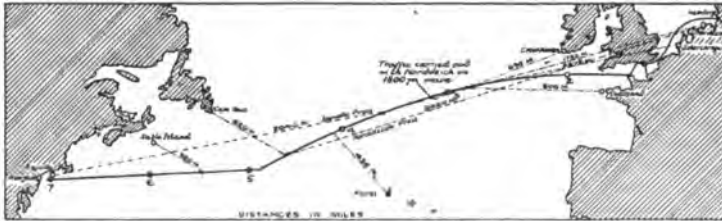


FIG. 131.—Communications of "Imperator".

Flores in the Azores was possible, which lasted until mid-day of the fourth day.

A break occurred upon the fourth day from mid-day until night as the Canadian station at Cape Race has only a range of 1000 km.

Communication with Cape Race upon the sixth day was discontinued, in favour of communication with Sayville, from when unbroken communication was obtained with the American Coast largely by means of the Telefunken station at Sayville upon Long Island.

The latest press news, given to the passengers in the form of a small newspaper, were sent at night by Nordeich, near Emden, and by the Telefunken station at Sayville direct to the ship.

During the journey to New York the "Imperator," usually without exception, obtains the Nordeich press messages until the night between the fourth and fifth days and then the press messages from Sayville until its arrival at New York.

Fig. 131 shows that it is possible for the "Imperator" to receive messages from Nordeich up to 4000 km., i.e. in the neighbourhood of the Canadian coast.

In the equipment of the station, it should be specially noticed that this is such that the "Imperator" is the first commercial ship in the world which is fitted with an aerial capable of economically utilising 1800 metre waves, the normal commercial wavelength being only 600 metres. This constitutes a great advance, as the "Imperator" could remain a much greater time in communication with Germany for the purpose of traffic than if fitted with only the 600 metre wavelength.

The 600 metre wavelength, by International regulations, is laid down for commercial traffic, but during the passage through the English Channel it was found that reliable communication could only be obtained from the 1800 metre wave owing to the English Channel being crowded with vessels working upon the 600 metre wavelength, which interfere with each other.

By international regulations this long wavelength can only be used when the ship is at least twenty-five nautical miles from the nearest coast station, in other cases the 600 metre wave must be used.

It has thus been shown that in the equipment of a commercial vessel of the size of the "Imperator" it is important to have a longer wavelength, more so than is the case with small ships.

This wavelength must, however, be above 1600 metres since the wave range of 600 to 1600 metres is reserved for naval requirements.

Owing to the number of vessels equipped with wireless telegraphy, which now begin to crowd in certain of the most important mercantile routes, it is evident that the discipline of the telegraphist must be very strict, and that new wavelengths will be required in the future in order to prevent mutual interference occurring in places such as the English Channel, which has been termed the wireless "Trafalgar Square" of Europe.

Naval Stations.—Whilst an installation radiating 7.5 kw. of energy is the largest yet installed upon any commercial ship, by special multi-wire aerials a first-class battleship can, owing to its size, be equipped to radiate twice this amount of energy, particularly since for naval requirements technical efficiency of transmission may be sacrificed for naval urgency.

Probably the largest wireless installations, from the point of view of actual radiated energy, ever installed upon a ship of any description, were five stations manufactured by Siemens Brothers

& Co. at Woolwich, and a description of one of these will suffice to explain the important features.

The source of current for these stations is a 30 kw. continuous-current alternating-current converter. The number of revolutions is about 1500 per second and the alternating current of 500 periods gives 1000 sparks per second. Current from the generator is stepped up from 400 volts to 20,000 volts by means of an oil-transformer which has a protective choke-coil shunted over the primary windings. A choke coil to complete resonance between the low-tension and high-tension circuits is installed.

The excitation circuit consists of a battery of oil condensers seen in the near right of Fig. 132 (Leyden jars were also used in two stations), four 12-gap spark-gap sets and a helical copper band inductance. Tappings upon this inductance coil are taken by means of a handwheel upon the front of the excitation circuit panel.

Each set of spark gaps is cooled by a separate small D.C. motor, driving a current of air through the ventilators seen beneath them.

The inductive coupling between the excitation circuit and the aerial is varied by means of a handwheel on the reverse side of the panel, seen to the right in the above-mentioned figure, which alters the position of the coils along their common axis.

The station is equipped for a normal transmitting wave range of 600 to 2000 metres, a very large shortening capacity being necessitated for the lower wavelength.

The aerial lengthening coils are seen to the left and consists of five horizontal separate coils, two of which, wound reverse to the others, can be raised or lowered by means of the handwheel upon the front of the second panel.

Tappings are taken off these coils for the various wavelengths, which are operated by means of another handwheel upon the same panel.

Exact tuning between the excitation circuit and the aerial is obtained by adjusting the wavelengths by means of the rotation of the handwheels upon the excitation circuit and lengthening coil panels, then altering the inductive coupling by a handwheel upon the primary panel and finally varying the relative positions of the coils of the lengthening coil, by means of the handwheel upon the lengthening coil panel, until the aerial ammeter indicates maximum current in the aerial.

Special features of the stations manufactured at Woolwich are an automatic starter for the motor-generator, which starts up



FIG. 132.—High-power naval station under construction at Woolwich.

[To face p. 266.]



the generator by means of an ordinary push switch. Provision is, however, made for starting the motor by hand if necessary. Duplex Relay apparatus, helium tube for controlling the spark gap, and a call-signal apparatus are also installed.

In each of these Siemens' installations a 5 T.V. station is installed as a standby station for work over comparatively short ranges and an 0.5 T.K. station as an emergency set, both stations working off separate motor-generators, the latter having a suitable accumulator battery.

Continuous Wave Ships Sets and Wireless Telephony.—Up to 1914 very little had been done regarding the installation of wireless telephony upon ships.

An Arco high-frequency machine had been installed largely as an experiment upon the "Vaterland," and it is likely that some of the few Poulsen-Arc generators, installed upon some ships for telegraphy, may have been adapted for telephony.

As far as the author is aware the Marconi Company had no telephony ship installations, until the close of the Telefunken-Marconi litigation allowed them to share in the results of Meissner's valve method of generating continuous wave.

The development of wireless telephony installations by both companies would afterwards appear to run a nearly parallel course. For example, the Telefunken Company just before the outbreak of war in 1914 were about to put a small wireless telephony installation upon the market, and after the outbreak of war in 1915 the Marconi Company put a similar type of instrument upon the British market.

Ships have been equipped with wireless telephony apparatus by both companies, but probably the former company's installations, utilising the hard Meissner valve, had advantages over the soft Round modification.

Except to mention that such valve transmitters can be used both for telegraphy and telephony and up to small powers have for telegraphy greater compactness than spark transmitters, whilst suffering from higher maintenance costs, it will be more convenient to defer their consideration to the chapter on wireless telephony in general.

One aspect of wireless telephony may, however, be dealt with here. Those whose practical experience of wireless telegraphy has been largely confined to army conditions and that chiefly with small continuous wave transmitters, should not rashly believe that wireless telephony will entirely replace wireless telegraphy, nor that valve telegraphy sets will replace the older,



more stable, and more robust spark-transmitters, which their respective manufacturers are by no means dropping.

A little reflection will show that, particularly for marine work, the general use of telephony installations would require a simultaneous adoption of some form of Esperanto. For example, a ship in, say, the English Channel would require an operator who not only must have a good conversational knowledge of English, French, and German, but also Dutch, Spanish, and possibly Italian, or otherwise hopeless confusion would result.

A man having a lingual knowledge, as distinct from a mere smattering or book knowledge, of such languages and also some technical knowledge, is unlikely to limit his activities to wireless operating. So there would be no source of operators to work such installations, at salaries it would be commercially possible to pay, unless it were on a very few transatlantic vessels where expense would not so much matter.

Up to the present day such lingual requirements have not arisen, since telegraphy utilises international Morse code, which can be sent or received irrespective of nationality.

Wireless telephony on board ship is therefore not likely to be general for a very long time, and from those able to correctly judge the future of wireless telephony, the author hears there is very little possibility of spark installations being abolished. It will, however, become the practice to also install valve installations (especially on ships having little space for accommodation) as well as spark sets.

Such valve apparatus will be used for telegraphy over short ranges for private messages in order to relieve the congestion which is now arising in longer range spark work, and they may be adapted so that, when on the high seas, ships of the same nationality, and otherwise as far as circumstances permit, will be able to engage in wireless telephony, having consequent advantage of greater quickness and utility.

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The preceding chapter is wholly written from actual manufacturing experience of practically all the apparatus described. For the convenience of those wishing for further information in this branch regarding Quenched-Spark and Telefunken installations the following references are given :—

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2. "Die Telefunken Zeitung."
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4. "Die Funkentelegraphie an Bord von Handesschiffen" (Thurn),
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6. "Drahtlose Telegraphie" (Schiffsinstallationen) (Bredow), "Jahrbuch der Schiffbautechnische Gesellschaft," 1912.
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CHAPTER X.

LAND STATIONS.

THE chief use of wireless telegraphy land stations is for communication with ships, there being (according to the International List of Radio Stations) a great preponderance of marine installations. While many of these land stations are for overland communication only, the majority are coast stations for the purpose of exchanging telegrams with ship installations. For this purpose they are scattered along all the commercial routes, and a vessel fitted with wireless is, as a rule, in communication with one or more coast stations, during the greater part of the voyage. These stations accept and send, at certain fixed rates, messages from the passengers, and messages dealing with the navigation of the vessel, such as warnings and weather reports. Many of the larger stations transmit weather reports and time signals regularly at certain hours for the benefit of all vessels within their range.

In the above service wireless telegraphy has no competitors. It is very questionable, however, whether it will replace overland and submarine telegraphy, since it is subject to natural atmospheric disturbances and also the intelligence is capable of being tapped. In cases of warfare, however, it has the advantage of being available when the submarine cables are interrupted, although its uses are restricted if other stations endeavour to "jam". It was, however, originally found during the Balkan disturbances and during the late war, that it is impossible to effectually "jam" messages, it being more effective to intercept the messages and to endeavour to decode them.

For overland communication wireless telegraphy has been largely used in certain tropical regions such as South America and in Arctic regions as Northern Siberia, where it is found impossible to lay telegraph lines owing to natural conditions and obstacles. It has also displaced wire telegraphy in regions where the sea bed is subject to continual disturbance which,

for only a restricted service, necessitates the continual repair of the cables, with consequent expensive upkeep.

Land wires in tropical regions are also subject to interruption by falling trees and hostile natives, the destruction of insulation by insects, disadvantages which do not occur in wireless telegraphy.

For these reasons the adoption of wireless telegraphy by the South American States has been very extensive. The Telefunken Company was the first to approach the serious solution of difficulties in connection with overland tropical installations, and the solution of such difficulties are possibly far more important than mere trans-oceanic communication.

The chief difficulty in the erection of tropical land stations is due to the fact that the wireless radiations are very largely absorbed by the forests, especially during the day. It is found that ships' stations upon vessels which voyage up the Amazon River to the centre of South America, while able to easily obtain ranges of several hundred miles by day during their passage across the ocean, when in the river are often only able to obtain much smaller ranges by night, and communication, even over only a few miles, is often totally impossible by day.

The explanation to this phenomenon is no doubt due to the surrounding virgin forests. It is now believed that a constant flow of electricity takes place in plants during sunshine, hence the new branch of electro agriculture due to that pioneer of wireless telegraphy, Sir O. Lodge.¹ This electrical flow passing transversely to the direction of propagation of the wireless waves is no doubt largely responsible for the difficulties experienced, which are also partly due to the ordinary ionising effect of the sun, which is increased in the Tropics.

Efficient communication in the Tropics can only be obtained by use of some form of musical note, such as the note of Quenched-Spark stations, which is able to be distinguished from natural unmusical disturbances of no definite wavelength. By means of the regular musical note, signalling can be carried on even when constant atmospheric are several times as intense as the actual signals.

The choice of the site of a wireless station necessitates the consideration of various physical, technical, and economic facts, and the result is often a compromise between the various requirements by the engineer upon the site, according to the needs of the most important factor.

¹ See a lecture before the Institution of Electrical Engineers, London, January, 1914.

The question of good earthing conditions is the most important. The most satisfactory earth is in sea water, but an earth in the ground water, if this is at a moderate depth, is also satisfactory. Marshy ground or soft meadow ground is very satisfactory if this is not objectionable upon hygienic grounds. If the site is near a river having a general direction to the direction over which communication is desired, the problem is simplified since the water of the river will tend to conduct the electrical waves.

Where it is totally impossible to obtain an earth, as in a rocky or a sandy district, or where a sandstorm may lay the earth bare, and if a better site is not available, an artificial earth or "counterpoise," consisting of a large area of wires of large capacity must be resorted to. This has the advantage of having constant electrical properties uninfluenced (unlike an earth in ground water), by the season, etc. It is not, however, adopted unless actually necessary, because of the consequent upkeep, though a compromise consisting of an earth and counterpoise is often employed. As a general rule in preference to a counterpoise an earth in ground water should be sought.

The lay idea which believes the best site for a wireless station is upon high ground is erroneous, since good earthing conditions can rarely be obtained at such sites. In such a site, consideration has also to be taken of the increased cost of conveying to the station materials and supplies to such heights.

The best position is usually at level ground in a wide valley with open country in the direction of communication. This site should be grass covered; since this indicates the presence of easily accessible ground water and the ground may then be cheaply turned up by ploughing for the laying of the earth wires, which often have a total length of some thousands of yards. If the site is in tropical forests, a space having only small trees is selected, so that deep lying roots will not interfere during earthing operations after the trees have been removed by burning.

These wires are, if possible, laid radially, or, failing this, they occupy a rectangular area which, if directive telegraphy to a single opposing station is desired, has the major portion of the longest side away from the direction of telegraphing.

The questions of obstacles in the direction of telegraphing must also be borne in mind. The simplest case of transmission over the sea is the one which most often occurs, and if obstacles are present in the form of mountains or land at the middle of the range these do not greatly interfere. When obstacles are,





FIG. 133 a.—Wireless station at Sandakan (British North Borneo)
(Siemens' Quenched-Spark system).

[To face p. 273.]



however, present, near to either the sending or receiving station so that one station lies in the "electrical shadow" of the obstacle, difficulties occur owing to the presence of the land shielding the station from the propagated waves.

It is also necessary to take into consideration various economic facts, for example, the accessibility of the site, whether the apparatus and masts can be transported to the site, and easy transport of supplies and stores when the station has been erected.

To obviate such difficulties of transport it is preferable to erect the station near a town, but if this is a large manufacturing town, with abundant large structures as chimneys, an electrical tramway system, or extensive telegraph wires, the station must, in order to avoid unnecessary loss of energy, be situated on that side of the town nearest to the opposing station.

Similarly, propagation will be best in that direction in which there is an absence of large towns. To avoid disturbance due to external noises and induced electrical currents, the station is best placed just outside the actual town, where land will also be cheaper. Electrical energy for transmission in such a site will be obtained from the mains of the town's supply and converted. Communication to the ordinary telegraph installation for further transmission of messages is obtained by a special land line.

A decision upon technical or economic grounds, as to the best site having been arrived at, it is necessary to erect buildings for the use of the personnel of the station.

These buildings are usually bungalows having living rooms for the operators, and outer office for the reception of telegrams, a room for the gas or oil engine supplying power, an apparatus room, and a room for the standby battery, which will be preferably placed in a separate but attached building.

A plan of such a station is shown in Fig. 133 *b* and an exterior view of the station at Sandakan (British North Borneo) is given in Fig. 133 *a*.

Masts and Aerials.—In Telefunken practice lattice masts are used to support the aerial. These are usually upwards of 200 ft. high, and their erection in places far removed from civilisation and its resources is a most difficult engineering feat. These towers are sometimes built up section by section, at other times a small mast is first built and a larger one which is connected to its base built in a horizontal position. The small mast is then used to obtain a purchase for pulling up the larger, the process

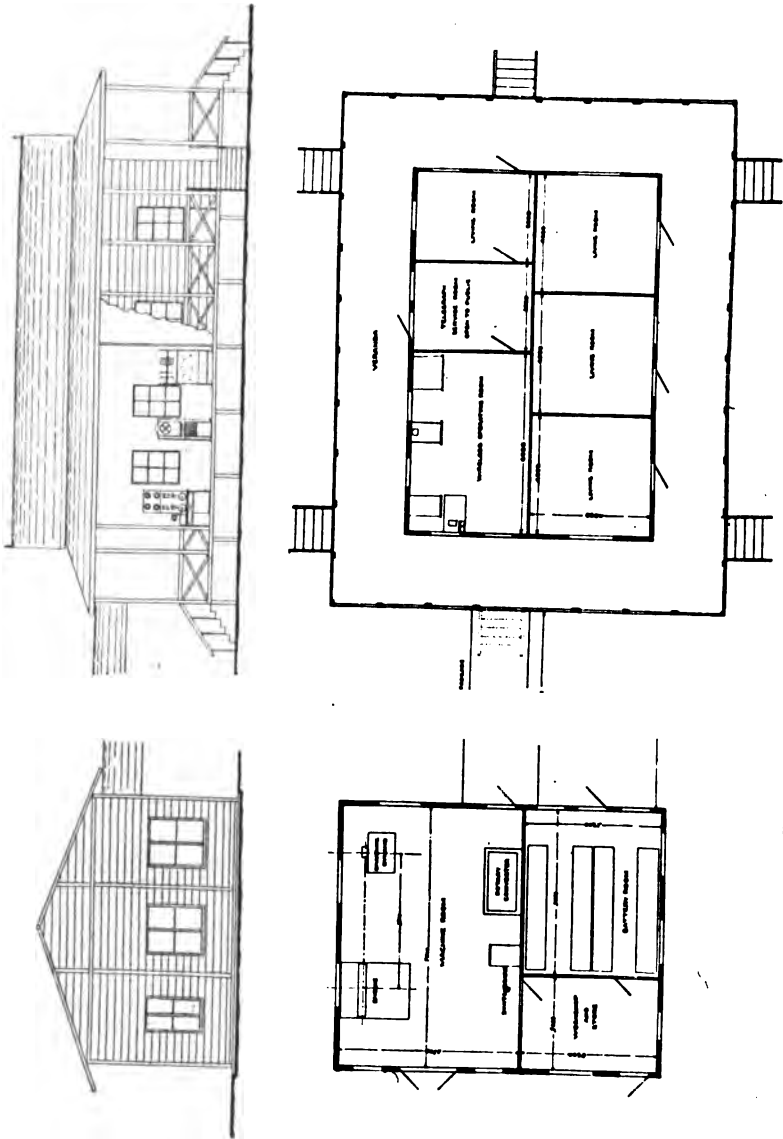


FIG. 133 b.—General arrangement of station buildings.

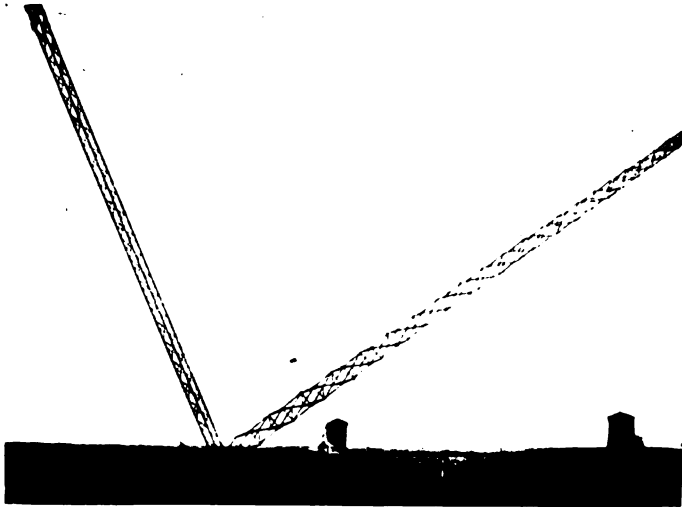


FIG. 134.—Erection of the Nauen masts.



FIG. 135.—Foot of aerial tower showing insulation from ground.
[See p. 275.]



FIG. 136.—Aerial anchorage of Quenched-Spark wireless station at Jesselton (British North Borneo).

[To face p. 275.]

being repeated if necessary. Fig. 134 illustrates this method of raising one of the masts being used during the erection of the Nauen station.

This method of mast erection is only rendered possible by the fact that the mast has a hemispherical bearing at its lower end, designed to facilitate erection, prevent strain on the base, and to allow the mast to be completely insulated from the earth. This bearing rests on a hemispherical cup which is itself carried upon a slab of marble or glass, sheltered by iron plates from rain and moisture. By this method the mast is completely insulated from the ground, and there is therefore no troublesome insulation necessary between the aerial and leading-in wires and the mast. A protective lightning switch is placed at the foot of the tower, so that during lightning storms aerial and earth can be directly connected for purposes of safety. The foot of such a tower is shown in Fig. 135. Stone piers are usually built beneath the masts for the purpose of jacking it up when it is necessary to replace an insulating slab. The mast itself is kept in position by a number of stays which radiate from it, and are anchored, after insulating, to a number of concrete piers around the circumference of a large circle, having the base of the tower as its centre. Such a pier is seen in Fig. 136.

The stresses set up in the mast by the wind during storms are very considerable, and a large factor of safety must be allowed in their design. This is usually based upon a wind pressure of 500 kg. per square metre, and a factor of safety of three is allowed.

The aerial for a land station is, to work with ship stations, usually either a T or L when directive telegraphy is required in a seaward direction, or otherwise an umbrella aerial. For the former types at least two high masts are necessary, while for the latter only one high mast and a circle of smaller masts which reduces the mast costs. The name "umbrella aerial" is given since the aerial wires radiate from the top of the towers in a similar way to the ribs of an umbrella. These wires are usually insulated at their lower ends and then stayed off to the masts carrying the counterpoise, if one is present. Such an arrangement is shown in Fig. 137, where the umbrella arrangement occupies an area of about $2\frac{1}{2}$ acres.

Occasionally different forms of lattice masts having an "Eiffel Tower" appearance are used, and in this case the aerial is entirely insulated from the tower.

Power Supply.—Should there be a town near the station

site, the necessary power for transmitting is obtained from the town's electricity station. When, however, the station is isolated it is necessary to install an oil engine.

For some of the largest stations, as in Australia, special

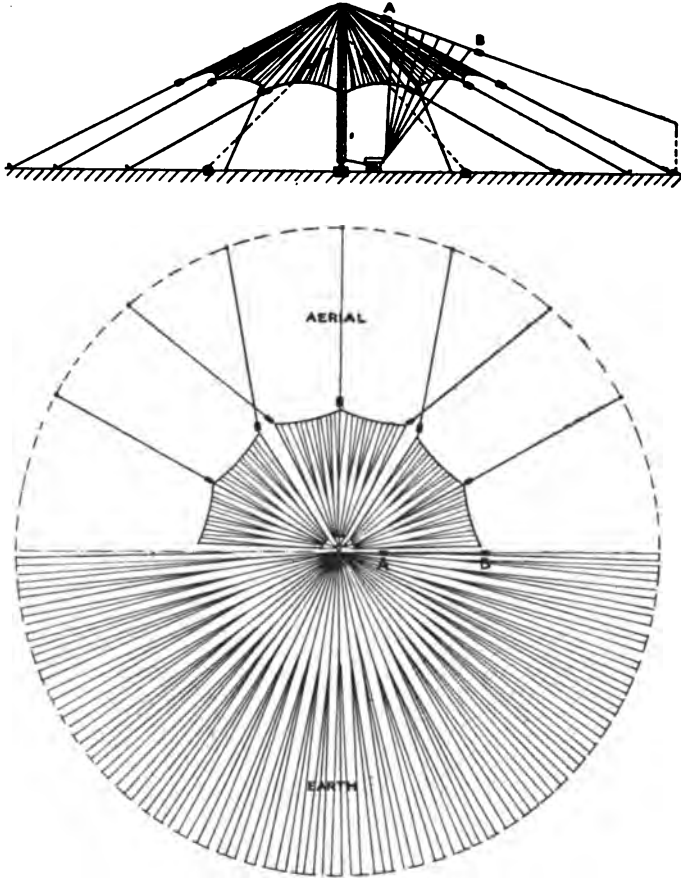


FIG. 137.—Umbrella aerial and earth arrangement.

electricity generating stations have been laid down. At some stations where oil engines are used, these are made to directly actuate by means of belts, a 500 period generator, but usually the oil engines drive a dynamo which is used to actuate the 500 period motor-generator when the traffic is heavy, and at slack

times to charge a battery of accumulators, from which transmission can take place either alone or with the dynamo and batteries in tandem. The latter method has the advantage that continuous running of the dynamo is not then necessary, and the running of the generator is far more regular than if directly coupled to the oil engine.

The Construction of a Wireless Station.—We may summarise the factors which have to be considered in the erection of a land station under the headings, political, climatic, technical, prime source of energy, nature of the range, nature of the site, availability of water, labour, and material earthing difficulties.

Under political will occur the purpose of the station, whether it can be installed with full scope to consider technical problems, whether it is for commercial purposes and is to be near a commercial centre and to work on commercial wavelengths, whether for military purposes calling for variable wavelengths, and strategic protection of the station by placing it inland, away from hostile war vessels, or if it is to be protected against hostile natives.

The technical considerations will include the aerial power necessary to obtain the desired range, the most favourable wavelengths, their limitations by the size of aerial it will be possible to erect, their limitations owing to the wavelength and system of opposite stations.

Considerations of prime energy will involve the possibility of obtaining electrical energy on the site, or by transmission from a distance, the voltage, periodicity, and power available with a view to its transformation to that required for the installation, and whether it will be subject to variations in voltage, etc., likely to cause bad and irregular wireless transmission and so necessitating a buffer battery. If electrical power is not available whether the best type of prime mover will be a steam boiler, using coal, wood, spirit or oil, or an internal combustion engine, using petroleum or petrol. In virgin country, the economic possibility of utilising a local waterfall might possibly be considered.

A contour of the range must be studied, since if the contour is sea the problem is simplified, if it is flat land, hilly or mountainous, the nature of the mountains, their height, their extent, their nature, whether bare, snow covered, or vegetated must be considered.

Nature of the site will include the immediate neighbourhood, whether any limitations of the site occur, and therefore limitation

of aerials owing to surrounding buildings, whether the land is sand, seashore, rock, meadow land, marsh land, with a view to the earth network and the weight to be carried by the foundations of the station buildings. In extreme cases, whether such building can only be carried out in the seasons when the ground is unfrozen or dry.

Considerations of water supply will include whether only sea or fresh water is available, if not, whether it can at small cost be transported to the site, whether it will be fit for drinking and accumulators, or if a distilling plant must be installed, also if it contains deposits, as chalk, iron, etc., likely to prevent its immediate use for boilers and condensers.

The actual geological nature of the station site must next be considered as to whether it can be ploughed up to bury the earth wires, whether it can be dug, or if it is rock and such a procedure is not possible, any limitations to the erection of a counterpoise caused by the neighbourhood.

Climatic conditions will include the considerations as to whether the air is dry or humid necessitating consequent lesser or greater insulation, whether typhoons, or tornadoes, or severe earthquakes occur calling for a greater factor of safety for masts and aerial, whether thunderstorms occur with great frequency likely to cause continual atmospheric disturbances. Whether Europeans will be subjected to any special tropical diseases, extremes of temperature variation, and any insect pests which may affect both personnel or the insulation of the apparatus so calling for special design.

During construction the following points must be considered in estimating the cost, the distance of the nearest population, whether local labour such as fitters, telegraphists, masons, carpenters, and navvies can be engaged locally, and the nature of the local tongue the selected supervising engineer must speak, whether there is likely to be any national prejudice to imported labour, and, if local labour cannot be employed, whether imported labour can be housed, or must be specially housed, and whether commodities will be available.

For construction certain materials may have to be transported, or may perhaps be easily obtained locally, such as building timber, poles, etc., necessary for the aerial and counterpoise which otherwise may have to be dressed from virgin wood. The possibility of stone, mortar cement, and ballast must also be considered.

Finally local transport difficulties must be considered in packing the station for transport, when the problem is simple if

local wharfs and cranes are available, and subsequent transport by railways or automobiles, but more involved if the material has to be transported over a difficult country by mules, sledges, canoes, or even porters.

Hence the problems which a wireless engineer will have to be ready to deal with are extremely varied, and whilst he must possess a very sound technical knowledge, far more than any advanced theoretical knowledge will he require knowledge of many allied subjects, tact to control labour of all conditions, infinite resource, and often personal bravery. It is not surprising, therefore, to find wireless engineering work followed by men for its adventure alone, and they are often the present-day pioneers of civilisation. Not a few have died in the performance of their duties.

The ship stations which have already been described, especially the higher power stations, are often adapted as land stations having short ranges. Such an installation in England is shown in the frontispiece to this book. The powerful land stations are designed according to the following table, which gives aerial energy and ranges by day and night over sea and flat land:—

RANGES.

Radiated Energy in kw.	Mast Height. Metres.	Normal Wavelengths. Metres.	Sea. (10% flat land.)		Flat Land.	
			Day.	Night.	Day. Kilometres.	Night. Kilometres.
			Kilometres.	Kilometres.		
2.5	60	600-1200	600	1200	450	600
5.0	85	600-1200	900	1800	600	1200
7.5	85	600-2000	1100	2200	800	1600
10.0	100	1200, 1650, 2000, 3000	1500	3000	1200	1800
15.0	100	1200, 1650, 2000, 3000	1800	3600	1500	2200
25.0	120	1200-6000	3000	4000	2000	2500
35.0	—		4000	6000 (20-25 %)	3000	4000
80.0 100.0	— —	} 1200-10,000	Germany to U.S.A., South America, Africa, Australia.			

These figures are approximate, since unlike ship stations the range of a land station is so dependent on the special conditions of intervening country.

Of these stations the 2·5 and 5·0 are similar in type. The 7·5 station is of the desk type similar to that installed upon the S.S. "Imperator," already described. The 10·0 and 15·0 T.K. stations are also very similar in form, but each of the higher power stations differ from one another. The highest power 100 T.K. is that installed at Nauen and a similar station has been installed at Funibashi in Japan, and a second one is now under construction in Japanese Manchuria.

The 2·5 and 5·0 T.K. Stations.—These stations obtain power from a 5·0 or 10 kw., 500 period alternator as the case may be. These are actuated by a suitable motor, driven from an oil engine and work at 3300 revolutions per minute, the speed being capable of variation to give a frequency of from 480 to 650 cycles per second at 220 volts.

The alternating current is transformed to 9000 to 12,000 volts according to the size of station, and feeds, through a high-frequency transformer, an excitation circuit as shown in Fig. 138.

This consists of a battery of Leyden jars supported upon an iron frame. Upon the front of this frame is supported the common excitation and coupling inductance and the Quenched-Spark Gap. The latter has below it a ventilating shaft through which air is driven by a small direct current motor, in order to prevent arcing of the gaps during heavy transmission. Beneath the motor at the foot of the stand, the make and break relay in the low-tension alternating current circuit is usually placed, but is not seen in the illustration.

Beside the excitation circuit frame is a second frame shown in Fig. 139. This carries the lengthening coils and shortening capacity. The former consists of four or five flat spiral conductors of which three are wound in one direction and fixed, and one or two are wound in the opposite direction and movable along the common axis. Tappings corresponding to the wavelengths to be used are taken from these coils to the back of the marble panel and lead to plug sockets seen in the front to which connection is made by the flexible lead from the centre socket. To tune the aerial circuit to the excitation circuit the movable coils are moved along the common axis, so varying their mutual inductance. The resonance hot-wire ammeter is mounted upon the side of this board and is calibrated to 40 amperes.

The battery of Leyden jars for the shortening capacity is mounted upon a board beneath this panel.

The remaining features of this station do not call for particular attention. The receiver is of the Universal type, and

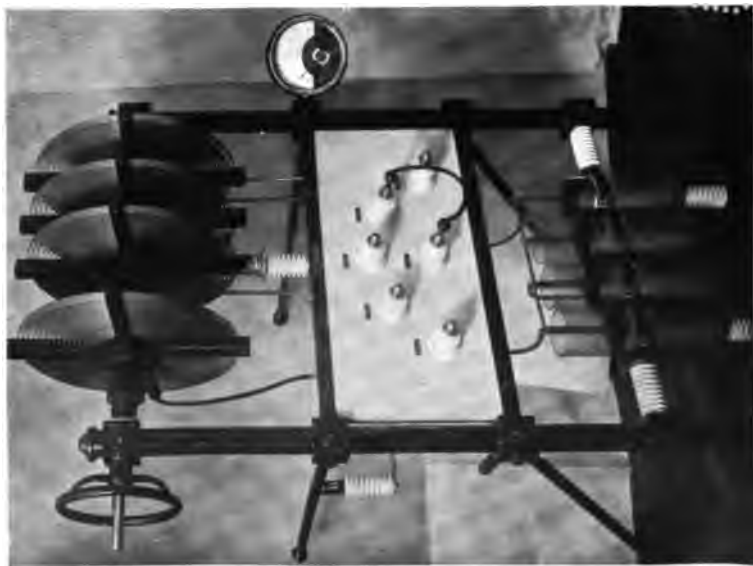


FIG. 139.—Aerial lengthening coils (2.5 T.K. and 5.0 T.K.).
[To face p. 280.]

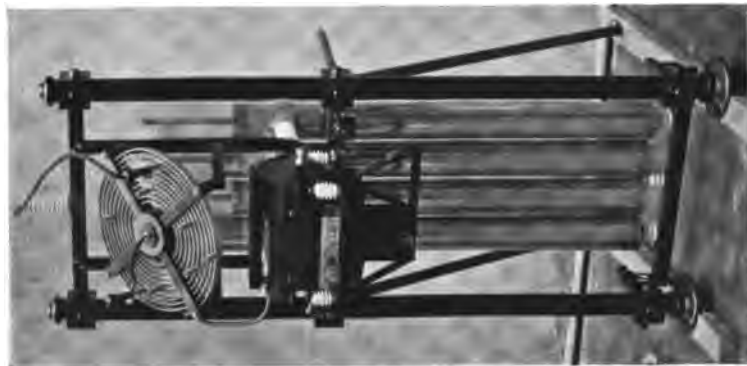


FIG. 138.—Excitation circuit (2.0 T.K.
and 5.0 T.K.).



Vertical line of dots on the right edge.

Small dot on the right edge.

Small dot on the right edge.





FIG. 140.—2.5 T.K. station at Ambon (Dutch East Indies).

[See p. 261.]

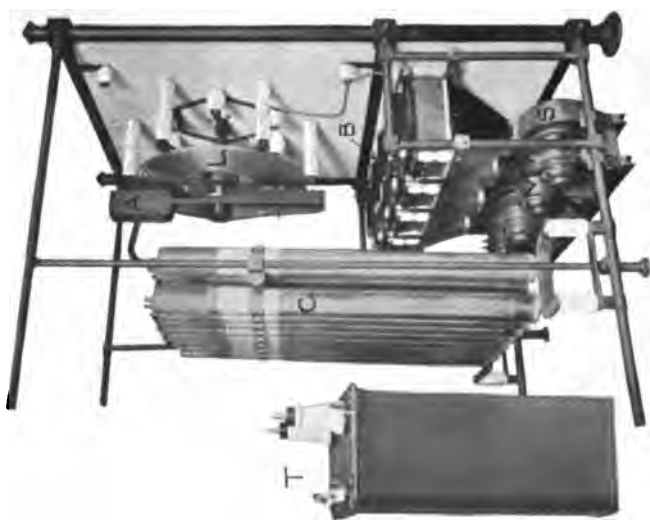


FIG. 142 *a*.—Back of excitation circuit panel (15 T. K.).



FIG. 142 *b*.—Back of aerial lengthening coil panel (15 T. K.).
[To face p. 281.]

various auxiliary devices, such as a rotating helium-tube to control the spark frequency, a Duplex Relay, etc. (see previous chapters), are often installed.

All the wireless apparatus can easily be installed in one room. Fig. 140 shows a 2.5 T.K. station of this type at Ambon in the Dutch East Indies, and a number of this type of station have been installed for the Government of British North Borneo by Messrs. Siemens.

The 10 and 15 T.K. Stations.—These stations are, as already mentioned, similar, except for the power of the source of energy and dimensions of the aerial.

Like the previously described type, they were specially built for work in the tropics (particularly in South America), and for this purpose they are constructed with the absolute minimum of wood and ebonite likely to be attacked by insect pests. The material used is metal and marble, which is also unaffected by a humid atmosphere.

They are arranged so that, with the exception of the care of the prime source of energy, both receiving and transmitting sides can be operated by a single telegraphist, and all parts are easily accessible.

This type of station is used for the largest type of coast station.

The source of energy is of 20 or 30 kw. direct current, according to the range desired, at 440 volts, which may be generated at the station or obtained from a local source of electrical energy.

This actuates a 500 frequency alternator of the normal type of appropriate dimensions, capable of speed regulation and often automatically started. The usual measuring instruments and special frequency-meter are fitted.

The transmitter, like the smaller stations described, consists of two parts, the excitation circuit and the aerial inductance, but since the energy used is much greater, their arrangement and size is somewhat different.

The Excitation Circuit is shown to the left in Figs. 141 and 142 *a*, the first photograph showing the front of the panel and the second the actual apparatus.

To this excitation circuit the energy, after being transformed from 440 to 20,000 volts by an oil-transformer, with protective coils and choke-coil to produce resonance, is led across the condenser battery C, formed of two rows of eight large Leyden jars, each having a capacity of 10,000 to 12,000 cm. capacity.

The spark gap consists of four sets of twelve-gap spark gaps B, each set of which is cooled by a small D.C. motor M driving a fan forcing air up a chute S between the gaps of each set.

The excitation inductance is a spiral of copper strip L, fixed with its plane vertical. Change of inductance is carried out by means of a series of plug sockets, operated from the front of the panel. Change of coupling is obtained either by having a counterpoised rotating sliding contact A worked by the handwheel on the front of the panel, if a direct coupling is used, or the same handwheel varies the relative co-axial distance of a second spiral if magnetic coupling is used.

The arrangement will be seen to be extremely simple, whilst giving very great mechanical strength and reliability. To avoid any danger of injury to the operator by the passage of any very extensive sparks the metallic frame is earthed.

The station is calibrated during construction for the wavelengths, 1200, 1650, 2000, and 3000 metres, and once fixed by a responsible engineer they cannot be varied otherwise than by the plug sockets, by the use of which no confusion can arise. These plugs make a short-circuiting connection between the lead at the back and any particular socket.

Two relays, in parallel, operated by a Morse key, serve to interrupt the low-tension circuit for transmission.

The Aerial Lengthening Coil arrangement is shown to the right in Fig. 141 and in Fig. 142 *b*.

Essentially it consists of five flat copper-band spirals, 1-5, arranged horizontally of which 2, 4, and 5 are rigidly fixed and 1 and 3 can, by means of the lower handwheel on the front of this panel, be raised or lowered relatively to the fixed coils, so causing a large variation of inductance. To render this mechanically easy to operate, the movable portion is supported by a steel wire which after insulation with several egg insulators is taken over a system of pulleys and the weight of the inductance is counterpoised by the weight W seen in the right-hand lower corner of Fig. 142 *b*.

As before, the length of inductance necessary to obtain any of the desired wavelengths is tapped off by heavy copper tubing and led to insulators, through which connection is made by a short-circuiting plug in the plug sockets seen on the front of the panel.

For the lower wavelengths used, a shortening capacity must be inserted. A handwheel at the top of the panel works a switch which places a suitable number of large Leyden jars,

similar to those used in the excitation circuit, in or out of the aerial circuit.

The high-frequency aerial ammeter of a very large type (80 amps.) is mounted on the centre of the panel.

It will be seen that the operation of this station is extremely simple. As with smaller stations, the motor-generator is run up, under control of the frequency-meter, to give the desired pitch of the transmitted note. The plug of the excitation circuit is then inserted in the socket marked with the desired wavelength and so serves to short-circuit the connections of that particular wavelength.

The similar plug-socket connection is made in the aerial panel after which the excitation circuit and aerial circuit is tuned by first rotating the handwheel on the first panel and then that of the second panel, a little further adjustment to the first handwheel being again necessary to ensure that the best coupling is obtained.

This tuning of excitation and aerial circuits is indicated by maximum reading of the aerial ammeter.

Stations of even this large size are practically noiseless in operation, whereas with an open spark or rotary-spark the noise would be deafening.

If much heavy traffic is carried out and the spark gaps need cooling, it is necessary to switch on the cooling fan motors during transmission and switch them out during reception by means of a push switch near the receiver, since their noise is many times greater than the noise due to actual sparking at the gaps. This objection is obviated, if the building permits, by placing the receiver in a separate room, but this necessitates two operators, one for adjusting the transmitter and one for telegraphy, although if change of wavelength is not frequently necessary one operator is still sufficient.

The aerial used for this station is an umbrella aerial having a capacity of 4000 to 5000 cm. for the 10 T.K. and of 5000 to 6000 cm. for the 15 T.K. station. The mast height is 100 metres, or with a T aerial this is formed by two 85 metre masts distant 130 metres apart. In the first case the aerial covers a circular area of 200,000 square metres and in the second a rectangle of side 50,000 metres.

The ranges which can be safely guaranteed for this type of station have been given on p. 279. For work with this type of station, to reduce the proportion of ebonite to a minimum for reasons already given a special form of tropical receiver has

been designed, which is mounted on a marble table having an iron framework. Such a receiver is shown in Fig. 143, and its component parts will be easily recognised. The switch to the left serves as a high-tension switch to break its circuits during transmission.

If the Universal Receiver is used with this station, a special receiver switch is inserted, since owing to the heavy voltage and consequent sparking the normally fitted switch contacts would be insufficient. Such an extra switch is either operated automatically by means of the ordinary change-over switch or by means of magnetic means or a spur-wheel gearing.

Those wishing for a description of the actual ranges and working of these stations should consult an article in the "Electrician" of 8th and 13th December, 1911, entitled "The Opening Up of the Amazon District by Wireless Telegraphy," which is too long to reproduce in this book.

The 25 T.K. Station.—This type of station has been installed at Perth and Freemantle, and the following description is taken by permission from an article entitled "Bridging Australia by Wireless," which appeared in the "Electrical Review" of 3rd January, 1913:—

"Shortly after the completion of the large Telefunken station at Pennant Hills, near Sydney, another powerful wireless station ordered by the Commonwealth of Australia was installed at Freemantle, and has now opened communication with Sydney across Australia, over a distance of about 2500 miles.

"The new station is situated on a hill between Freemantle and Perth, on the southern bank of the Swan River. The hill, 136 ft. in height, is one of the highest in the neighbourhood, and is covered with woods, like the surrounding country. The station covers an area of 600 square metres, and is situated $4\frac{1}{2}$ miles from the sea.

"While mainly intended for purposes of defence, the new station is controlled in time of peace by the Postal Department, and is used almost exclusively for commercial telegraphic service with merchant ships and for the meteorological intelligence service. Since Freemantle is an important harbour, being the first point of connection for traffic via Colombo and Cape Town, the station is likely to render valuable services to navigation.

"The centre of the area covered by the station is the highest point, and the tower there installed serves to carry the antennæ. This iron tower, 120 metres in height, is designed on the well-known Telefunken system, standing on a ball bearing, insulated



FIG. 141.—Front of excitation and aerial lengthening coil panels (15 T.K.).
Siemens Bros. & Co., Woolwich.

[See p. 282.]



FIG. 143.—Tropical type receiver.

[To face p. 284.]





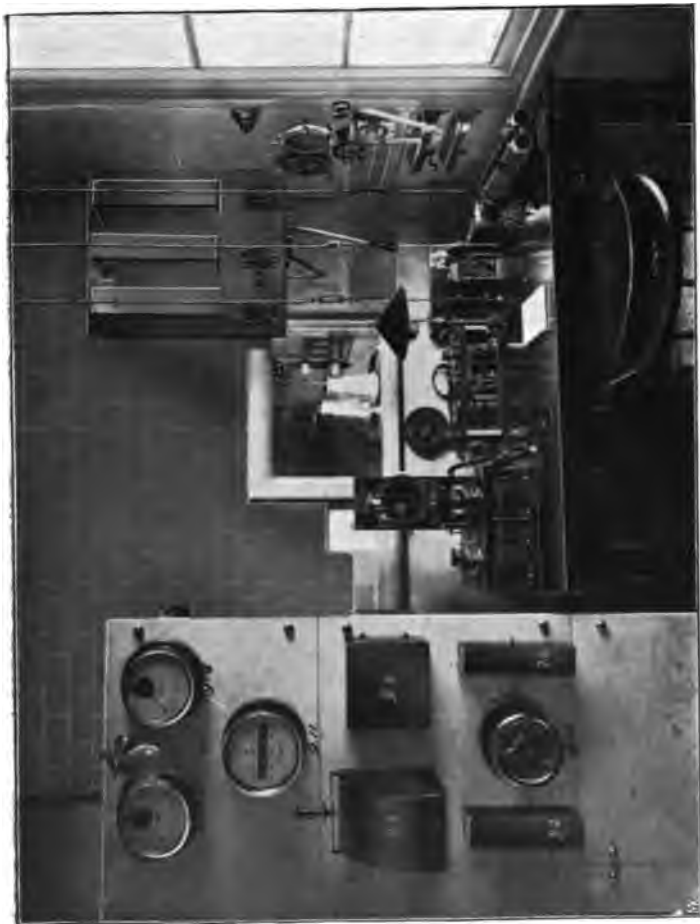


FIG. 144.—Receiving apparatus (Freemantle).

[To face p. 285.]

from the ground by means of glass insulators, and is kept in equilibrium by three pairs of cables moored to concrete blocks, 150 tons in weight. Glass plates are used as insulators, and the antenna system, insulated from the tower, is arranged in umbrella fashion and comprises phosphor-bronze wires 3 mm. in diameter, joined up in three sets.

"The leads enter the tower at 10 m. apart, parallel to one another. Each of the three sets is arranged between two pairs of tower cables, thus allowing the wires to be readily kept clear of these cables with a minimum elastic stress in the wires.

"Since the sandy soil is extremely dry in summer (there is absolutely no rain during the six or seven summer months), while the underground water is at a depth of 42 m., much difficulty was experienced in establishing a satisfactory earth connection. An insulated counterpoise was therefore used, consisting of about 100 wires, 300 m. in length (phosphor-bronze of 2 mm. diameter), which radiate from the tower at 9 m. height, being insulated by means of four insulators arranged in series.

"The wires are supported by three bronze wire circles suspended from telegraph poles, at 100, 200, and 300 m. respectively from the tower. The first circle comprises 12, and each of the others 24 telegraph poles; the first is 7.2 m., the second 5.4 m., and the third 3.6 m. in height, so that the counterpoise gradually approaches the ground, which assists in endowing the vibratory circuit formed by the antenna and counterpoise with a more open shape, thus ensuring a more satisfactory radiation and a more outward reflection of the wave from the counterpoise.

"In 16 wires of the counterpoise, the first 100 m. have been left out, and the free space thus obtained contains the buildings and the wires connecting the antenna with the apparatus house. In addition to the large umbrella antenna ($\lambda = 1400$ m.; $C = 4450$ cm.), which serves for the sending and receiving of waves upwards of 1600 m. in length, two T-antennæ for waves of 600 to 900 m. and a T-antenna for waves of 900 to 1600 m. have been provided. The T-antennæ are arranged opposite one another, thus eliminating any screening effect of the tower and allowing the antenna situated in the most favourable direction with regard to the corresponding station to be used. One end of these antennæ is fixed to, but insulated from, the tower, the other being attached to a steel wire sub-divided by insulators and stretched out from the tower. The points of suspension are situated at a height of 60 m., the horizontal part being 2×25 m. in length. The constants of the two-wire antennæ for waves of 600 to 900 m.

are: $\lambda = 570$ m.; $C = 1000$ cm., and those of the four-wire antennæ for 900 to 1600 m.: $\lambda = 750$ m.; $C = 1600$ cm.

"The station has its own generating plant, which is installed in a special room 25 m. from the reception building, so that the noise of the machinery and driving belts does not interfere with the receiving of telegrams.

"The power plant includes an alternator of 60 k.v.a., at 500 volts and 500 cycles, driven by a four-cylinder Gardner oil engine of 75 h.p. The engine runs at a speed of 500 r.p.m., and the alternator at 1500 r.p.m. Leather belts are used for power transmission, the distance between centres being 9.6 m. The engine can be fed with kerosene or gasoline, and compressed air is used for starting. Three water tanks are provided for cooling the cylinder. A continuous-current dynamo of 3 k.w., also driven from the oil engine, serves to excite the alternator and to actuate the relays.

"The wireless apparatus is installed in two rooms in a special building. One of these rooms contains the receiving table and switchboard, the Morse keys and switches actuating the high-pressure senders in the other room being installed on and beside the table (Fig. 144).

"The operator is able to control from his table the whole of the apparatus, while getting through a window a good view of the high-pressure apparatus and antenna ammeter. On the left hand is arranged the receiver, 54, and on the right the key, 10, actuating the sender relay and the pressure regulator of the high-frequency machine. To the right on the front wall is situated the remote controlling gear of the variometer, 26, and the sound tester and emergency receiving coils are suspended from the side wall. Other apparatus installed on the table are the call bell, the wavemeter, 38, for testing the received signals and a contact button for actuating a signal bell in the power house. The receiver is equipped with an intermediate circuit and three parallel antenna condensers filled with oil.

"The sending apparatus (Fig. 145) comprises an A.E.G. high-pressure oil transformer, 13, for a ratio of 1:120, a condenser battery, 43, of 36 Leyden jars connected up in series, six sets of Quenched-Spark Gaps, 20, each consisting of 16 sections, and a primary variometer, 17. Two primary inductance coils, 24, are used to determine the resonating position between the alternator and the high-pressure transformer, two secondary inductance coils protecting the transformer against high-frequency currents. Variable flat copper coupling coils, 14, are used to connect the closed



FIG. 145.—Transmitting apparatus (Freemantle).

[To face p. 286.]



vibratory circuit with the antenna circuit, 15. A hot-wire ammeter, 18, in the antenna circuit, which can be observed from the operator's seat, indicates the current intensity in the antenna.

"The capacity of the condenser battery is 11,000 cm.; in the case of long-wave operation two sets of jars are cut out, thus increasing the capacity to 16,500 cm. A fan for cooling the plates has been provided for each two sets of spark gaps.

"As the high-pressure switch of the receiver and that of the high-pressure compartment are so arranged as to be handled simultaneously with the left and right hands respectively, only a second is required for switching over from 'sending' to 'receiving,' and inversely. The switch at the same time actuates the spark-gap fans and the sender relay.

"The new Freemantle station has been in operation since June last, and will shortly be taken over by the Government. In addition to communication with Sydney and with passing vessels, a regular press service is carried on twice a day."

With this type of station (250 T.K.) the ranges guaranteed by day with favourably long wavelengths (1200, 1600, 2000, 3000) is 4000 km. over sea (including 20 to 25 per cent. land), or 2000 to 2500 km. over land only, with the exception of the unfavourable periods of dawn and sunset.

With the Freemantle station, however, communication is carried out over a distance of 4500 km., mostly over land. The similar station installed at Sydney has obtained ranges up to 6000 km. over sea.

More recently, according to the "Electrician" of 1st February, 1918, Commander Cresswell, of the Australian Navy, has stated that both these stations regularly receive the Nauen station in Germany over a distance of 7000 miles, so constituting, for the Nauen station, a record in wireless transmission.

The history of these two stations which form the basis of the development of wireless telegraphy by the Australian Government, under the care of their engineer, Mr. Basillie, is interesting.

When the contracts for these two stations and for other stations in New Zealand were placed, such contracts were warmly contested in the respective Parliaments and as warmly defended on the score of greater efficiency and economy of expense.

Patent litigation was commenced by the Marconi Company against the representatives of the Telefunken Company in Australia and the Australian Commonwealth Government.

After the Telefunken-Marconi agreement to mutually settle their respective patent litigation, the case against the Telefunken

Company agents automatically lapsed. The concurrent case was settled by the Australian Government on the Marconi Company agreeing to withdraw their action on the payment of the sum of £5000, for which they themselves agreed to permit the use by the Australian Government of their various patents, should the Government so desire.

The 35·0 T.K. Station.—This type of station was that formerly installed at Nauen, but was replaced in 1912 by an 80 T.K. and still later by a 100 T.K. station which will be next described.

The aerial when non-directive is an umbrella aerial supported by a mast 150 metres high, and 15 smaller masts 30 metres high, arranged in a circle of 450 metres radius.

The source of energy is 100 h.p. D.C. motor which drives a 60 h.p. A.C. generator giving current at 440 volts, 500 periods at a speed of 1000 revolutions per minute, the usual method of varying the speed being used to regulate the spark frequency and note of the transmitter. Alternatively when D.C. current is not available, two oil engines each of 100 h.p. output and each driving a 60 kw. D.C. generator are used, together with an accumulator battery with sufficient output to aid the generator when the station is working at full load, or to work it unaided for three hours.

The current from the generating mains is transformed from 440 volts to 50,000 volts by means of an oil transformer, 1, which may be seen, with its protective choke coils, 3, behind the switchboard in Fig. 146. The relays, 2, for interrupting the 440 volt circuit can also be seen upon the bench in front of this illustration.

The spark gaps may be seen in Fig. 147 and consist of eight sets of ventilated 14-gap spark gaps, any six of which may be used. They are numbered 1. The excitation circuit has a battery of 90 Leyden jars, 2, which are so connected as to have a capacity of 40,000 metres. The inductance coils, 4, have a portion, 3, which may be varied relatively to alter the coupling. Tappings to the excitation inductance are taken by a switch which engages above the large insulators. The aerial lengthening coil, 5, is seen towards the left, being of the usual 5-coil type. There are five plug sockets upon the excitation inductance and lengthening coil for the wavelengths 2000, 2500, 3000, 3500, and 4000 metres.

The spark frequency is controlled by a rotating helium tube seen above the aerial lengthening coils.



FIG. 146.—Back of switchboard of 35 T.K. station.



FIG. 147.—Transmitting apparatus of 35 T.K. station.

[To face p. 288.]



The receiver for this station actually consists of two 2000 to 6000 metre receivers with intermediate circuits, together with a tone intensifier, call-signal apparatus, etc.

The range of this station for wavelengths of 2000 to 4000 metres is 2400 miles by day and 3600 miles by night over sea or 1800 miles by day and 2400 miles by night over flat land, but is dependent on the geographical position of the station, the climate, and other factors.

This station, when superseded by the much higher power station at Nauen, was re-erected at Sayville, near New York, for transatlantic work. A description, after its re-installation, was communicated to the American Institute of Radio Engineers by A. Seelig, from which the following is abstracted by Eccles :—

"*The Mast* is a steel lattice of triangular section, 150 metres (500 ft.) high, with a ball and socket joint at the bottom and with one about three-quarters the way up. This type of mast is much used by the Telefunken Company, and more than 20 have been erected. The mast is insulated from the ground by a large glass insulator, and it is guyed by linked steel rods carried to two sets of three concrete and brick anchorages, one set spaced on a circle of 235 ft. radius and the other on a circle of 430 ft. radius. Heavy glass insulators are provided at the bottom of each guy.

"*The Antenna* is a 12-wire umbrella divided into two groups of six. Each antenna wire has a separate vertical lead. The outer end of each antenna wire is tied to a large bell-shaped insulator attached to a steel wire rope. These ropes are attached to the mast at the top and two wooden poles, about 30 ft. high, at the bottom. The poles form a circle of approximately 2300 ft. diameter. The steel ropes are sub-divided into six sections by porcelain insulators of the egg type. The antenna wires and the vertical leads are of hard-drawn copper.

"The capacity of the antenna is about 10,000 cm. and the natural wavelength 1800 metres. When tuned to 3000 metres the antenna resistance is 3 ohms.

"Instead of an earth a counterpoise network is used consisting of 56 wires about 16 ft. above the ground, radiating from a centre for a distance of about 1000 ft. The antenna, the counterpoise, and the mast itself are provided separately with lightning switches for connecting them to earth during storms.

"*The source of power* is the network of the Long Island Lighting Co., who supply 2300 volts at 60 cycles. This is stepped down to 440 volts before entering the station building,

where it drives the main motor-generator charging set. This set, made by the General Electric Co., consists of an induction motor driving a 220-volt direct-current generator, which charges the 600 ampere-hour storage battery. From this battery the entire station draws its current. The battery current may be utilised to feed two different 500-cycle motor-generator sets, one with a motor of 75 h.p., the other with a motor of approximately 15 h.p. The smaller set is used for ship and shore communication. The voltages of the large generator are 600 on open and 350 on closed circuit. It is of the special inductor type developed at Nauen, and its efficiency is about 80 per cent. The power factor is 0.8 at full load.

“ The generator room is separated from the transmission room by a control room, the partitions being largely of glass, so that the electrician in charge is enabled to see both the generating and transmitting equipment. The transmitting equipment takes 60 K.V.A. 500-cycle single-phase current from the high-power generator. The main transformer raises the voltage to about 60,000. A simple hand and solenoid switching device placed between the generator and the transformer when opened disconnects the transformer and the entire transmitting apparatus without stopping the generator or reducing its field. The high-voltage secondary of the transformer feeds the primary oscillating circuit through a series choke coil, which protects the transformer from the oscillations in the high-frequency circuit. The capacity of the primary circuit is made up of Leyden-jars arranged in five groups, partly in series and partly in parallel, the capacity of each jar being 10,000 cm. and the total capacity of the battery 40,000 cm. They are of the standard Telefunken type—that is to say, long and narrow, with tinfoil coverings on glass $\frac{1}{4}$ in. thick. At full load about 40 kw. are drawn from the transformer. The discharge takes place through 40 or 50 Quenched-Spark gaps in series. The gaps are held in eight frames arranged on a stand, and a motor-driven blower is provided for cooling; the distance between plates of each gap is about 0.1 mm. to 0.2 mm. The plates are of the ribbed type, having four or five concentric circular ribs.

“ The primary inductance is coupled in part conductively and in part inductively with the inductance of the antenna circuit. The coupling is variable, the adjustment being operated directly from the control room by a handwheel and a system of sprockets, chains, and levers. The antenna current is about 120 amperes when the power supplied to it is 30 kw. to 35 kw. The efficiency

between generator and antenna is estimated at from 75 to 80 per cent.

“Operating.—The transmitting key operates a relay for making and breaking the transformer primary circuit. The main relay is installed in duplicate. Each of them has eight contacts cooled by an electric fan. The 220-volt battery current is used to energise the coils of the relays and other automatic control devices. At each switch over from sending to receiving a large number of operations must be performed. Provision must be made that when the antenna is connected for receiving sparking is impossible, even by the operator closing his key. Again, if the small set is working, the high-power apparatus must be entirely disconnected, and vice versa, without necessarily stopping the generators. In changing over from receiving to sending, it is necessary to disconnect the receiver, to transfer the antenna connection from receiver to transmitter, and to close the relay contacts which are on the transformer supply circuit. In order to perform all these functions successfully, about 100 wires were laid between the two rooms. The automatic antenna switch, worked by the operator's foot, accomplishes most of these things. Each successive pressure alternately switches the antenna from the receiving to the transmitting circuit and vice versa. The operating room is separated from the rest of the station by sound-proof walls and double doors. The receiving apparatus and transmitting keys are mounted on desk-like tables, and in order to avoid confusion all the apparatus handled, such as keys, switches, levers, knobs, and plugs, have been painted either red or white, according as they belong to the high-power set or the smaller set.

“The Receiving Apparatus is of the standard Telefunken upright type. An interesting part of the plant is that for duplex reception. A simple device alternately connects first one and then the other receiver to the antenna at a high frequency, so that each receiver is in circuit three or four times during the making of a Morse sign. With a little care this device is easily arranged to receive simultaneously three messages on different wavelengths. The Telefunken sound intensifier is also installed. This is a resonance microphone relay (see p. 147). By means of several intensifiers in tandem a detector current of 10 milliampères can be increased to one of 10 amperes or more. Besides intensifying, the use of this apparatus increases the selectivity by its utilisation of acoustic resonance.

“The station is provided with automatic transmitters utilising

punched tape. Press messages from Sayville despatched at nine o'clock in the evening have been received at Gibraltar, a distance of 3200 miles."

Later this station was fitted with a continuous wave transmitter of the Arco type, in order to carry out continuous wave work with Nauen. It could be heard most of the day and night engaged in such traffic during the early days of the war. When the United States entered the war, it was taken over by the United States Government in whose possession it still remains.

The Long-Range Station at Nauen.—The experimental station of the Telefunken Company at the village of Nauen (about twenty-five miles from Berlin) is the most powerful wireless station in the world.

The station was built in 1906 and has been constantly reconstructed and improved, and the expenditure before the late war for experimental work was about £60,000 per year, said to be partly borne by the German Government.

When originally built the radiated energy was only about 10 kw., and the transmitter, not making use of the then undiscovered Quenched-Spark gap, did not have an efficiency above 25 per cent. The first installation made use of four powerful induction coils for the production of oscillations which discharged a battery of 360 Leyden jars 20 times per second, these jars occupying very considerable floor space.

The advantage which resulted by the introduction of later apparatus can be estimated by the fact that a new equipment installed in 1911 required only 36 Leyden jars, which were discharged 1000 times per second, and gave over three times the output.

The aerial tower when first built was 100 metres high, the greatest ranges obtained being from 1900 to 2200 miles.

Owing to the station being built on flat damp ground it was possible to obtain a very good earth in the ground water at a depth of 6 ft., but rendered it difficult to obtain a good foundation for the heavy tower.

This tower, supporting an umbrella aerial, consisted of the usual lattice mast, triangular in section, each side being 4 metres in length. The three main vertical members were formed of riveted sections 8 metres long bolted together and connected by diagonal struts.

The usual ball and socket joint and layer insulation was provided, the tower tapering at a height of 6 metres. This rendered it unnecessary for the aerial to be insulated from the tower which thus formed part of the oscillatory system.

Three guys were used to maintain the mast vertical, these being attached to the mast at a height of 75 metres, and were iron rods linked together and anchored to stress piers 200 metres from the mast, insulated by massive glass insulators at the piers and in oil at the tower. A stairway permitted the tower to be ascended.

The aerial consisted of six sections, controlled by three pairs of pulleys manipulated from a platform on the tower at a height of 96 metres. These sections were so arranged that each one was counterbalanced by the opposite section, thus subjecting the tower to a minimum stress and equalising any unsymmetrical stress.

The lower ends of the aerial were carried to 15 masts 30 metres high, where they were insulated by Rendahl insulators (p. 95).

The leads to the station house from the top of the mast consisted of 154 wires in the form of six grids held on wooden battens, and were taken to a bus-bar and hence through a high-tension insulator to the apparatus room.

The current in the aerial was 50 amperes and the natural damping of the aerial 0.14.

The earth consisted of 108 iron wires of total length nearly twenty miles, buried 18 in. below ground and covering an area of 280,000 square metres.

In 1911 the steam plant was increased to 100 h.p., and a standard 35 T.K. station, described in the last section, was installed which permitted distances up to 3100 miles to be bridged.

At the end of 1911 it was proposed to increase the aerial energy to 80 kw. and to increase the height of the aerial to 200 metres by superimposing a second lighter tower of 100 metres with a separate ball and socket joint on the one already present.

This work, a feat of civil engineering, since while building heavier foundations it was necessary to support the mast (then 170 metres high) in the air for several weeks, was successfully carried out.

The umbrella consisted of 36 bronze wires each 200 metres long, anchored to 30 auxiliary masts 30 metres high arranged in a circle of 400 metres radius. The sag of the wires was so slight that the ends of the active wires were more than 100 metres above ground. The aerial covered 500,000 square metres at least, a quarter of this area being effective in giving the large capacity required.

The earthing arrangements were also improved. Owing to the marshy nature of the ground the new buildings were erected on a system of 200 iron piles, each of which was fitted with copper earthing plates rammed down into the ground water.

In the early spring of 1912 a severe storm, before the completion of the new plant, caused the upper 100 metre mast to fall, and during its fall it carried away one of the stays of the lower mast, causing the fall and destruction of the complete mast, but doing no damage to the station buildings.

At this time it was proposed to carry out experiments between Nauen and Togo in German S.W. Africa. For this reason the umbrella aerial was not rebuilt, but a directive aerial constructed. This aerial is shown in Figs. 148 *a* and *b*. It is supported by five towers each 120 metres in height, two of which serve to strain off the aerial proper.

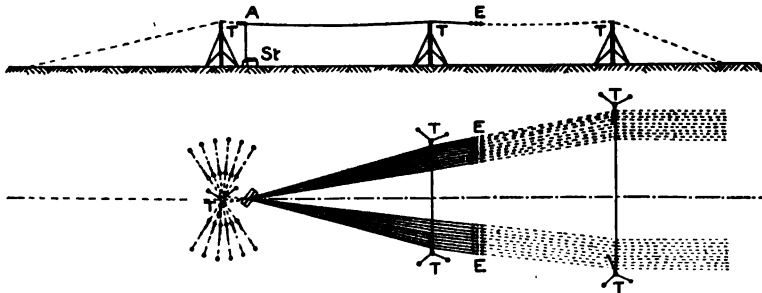


FIG. 148 *b*.—Arrangement of Nauen Aerial, 1914.

The single tower near the station is also equipped with an umbrella aerial for working with short wavelengths over comparatively small distances.

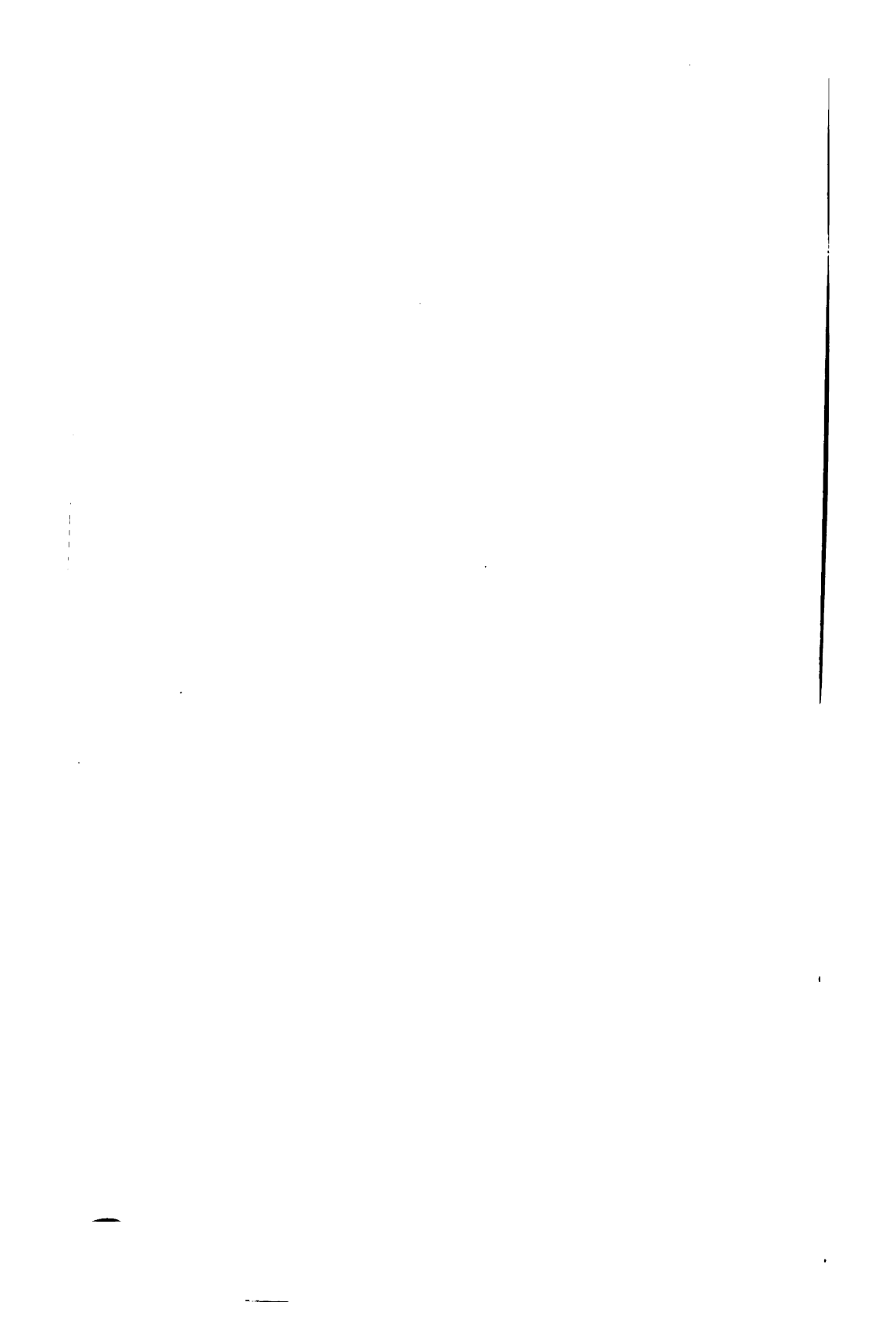
The equipment when completed, permitted an aerial radiation of 100 kw. and the station to attain a range of 9000 km. over Europe, Africa to off the coast of S. America, and for regular communication at night to be carried on between Nauen and Togo. Also, although propagation to the United States must be carried out with the aerial in the worst possible direction for this purpose, until Sayville was closed by the United States Government, daily communication was obtained. More recently, as already mentioned, it has been regularly received in Australia.

A high-frequency machine radiating 100 kw. was installed in 1913 for work with continuous waves and a wireless telephony transmitter, which in 1913 with 6 kw. radiation enabled con-



FIG. 148 a.—View of Nauen station.

[To face p. 294.



versations to be carried on from Nauen to Vienna, a distance of 400 miles.

The requisite enlargement of the high-frequency excitation circuit, in order to produce an antenna energy of 80 kw., necessitated a correspondingly increased source of primary energy.

It was not necessary to install new engines and dynamos as connection was obtained with the electricity works of the East Havelland district. The current is carried from here over a distance of 30 km. by means of overhead wires. The current is three-phase alternating current at a pressure of 15,000 volts. The last 400 metres of the connection consist of H.T. cable laid underground in order to avoid inductive disturbances from the aerial.

At the point where the overhead wires are joined to the underground cable, a switch station is situated, as the distributing system is carried out with double connections in case of breakdown.

The H.T. 15,000 volt three-phase current is transformed down after entering the wireless station and is subsequently converted into 220 volts continuous current.

The plant comprises the requisite oil-filled transformers overload cut-outs, high-tension and lightning protective devices, the pressure and current measuring instruments, and the recording wattmeters and wathour meters. The plant is designed for an output of 300 to 350 kw. The whole plant is divided into two parts in order to gain the advantage of a certain reserve in case of breakdown, and to be able to work with half the total output when less energy is required.

Two three-phase transformers are installed, each for 150 kw. output. These give 120 volt three-phase current on the L.T. side. Two converters of single armature type each for 150 kw. output convert the three-phase current into continuous current at 220 volts. These converters can be connected either singly or together to the main bus-bars, from which the current is distributed.

In order to have a certain reserve of primary current, the existing steam generator set of about 100 h.p. is retained and an enlarged accumulator battery has been installed. These two sources of energy are sufficient even if the three-phase supply fails altogether to provide a continuous current supply of 80 to 90 kw. intermittently, and this is sufficient for short periods even for long distances. Under normal conditions the battery is used

principally for lighting, and is charged by a special auxiliary dynamo.

All the mains are led to the L.T. switch gallery which is in two parts. This gallery is reached by means of steps, so that from the gallery the whole of the machine room can be conveniently seen. The left-hand part of the gallery is provided with four panels and is reserved for continuous current distribution. One panel is provided for the switch gear of each of the two three-phase continuous current converters, a third panel for the accumulator battery and charging dynamo, and the fourth panel is vacant and is held in reserve for future requirements (Fig. 149).

The right-hand half of the switch gallery contains the starting and regulating apparatus and the instruments for the main converter which converts the continuous current from the bus-bars into alternating current of 500 periods per second, as is required for the generation of singing sparks.

This set consists of a 300 h.p. continuous current motor with commutating poles running at a speed of 1000 revolutions per minute. The speed of this machine can be varied 20 per cent. in either direction. This motor is direct coupled to and mounted on the same bed-plate with a 250 K.V.A. alternator. A small 50 period generator for an output of 200 watts is also driven directly from the main shaft of the converter and serves to operate a speed indicator (helium tube) on the switchboard.

The most important and the most interesting part of the new installation is the apparatus for producing high-frequency energy. This apparatus is situated in one wing of the station house, which contains in addition to the high-tension room the central operating room and also the room for the receiving apparatus.

The transmitter consists of the transformer B, the condenser battery D, four frames of Quenched-Spark Gaps C, and three large frames E containing the self-induction coil for the excitation circuit and the aerial variometer (Fig. 150).

The transformer B is oil-insulated and designed to deal with the whole 250 K.V.A. and transforms the pressure of the 500 period alternating current from 1000 volts to 75,000 to 100,000 volts. The large output and high pressure have necessitated the transformer being of such dimensions that it was found advisable to place it on the cellar floor so that only the top of the transformer with the porcelain leading-in insulators projects into the transmitting room (Fig. 150).



FIG. 149.—Generating plant at Nauen: A. alternator; B. generator.

[To face p. 296.

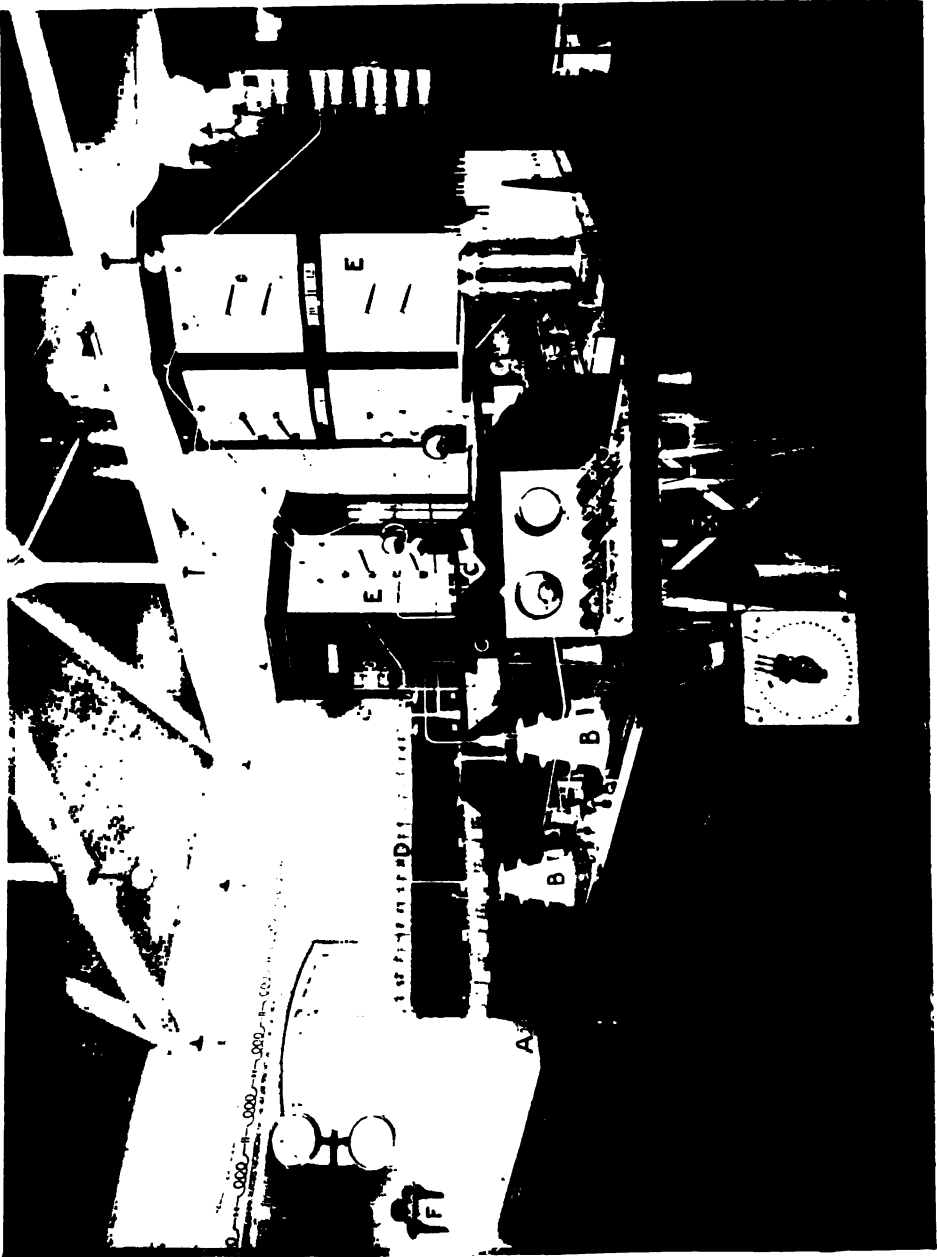


Fig. 150. -Transmitting apparatus at Nauen.

(See p. 296.)





FIG. 151.—Condenser battery (Nauen).

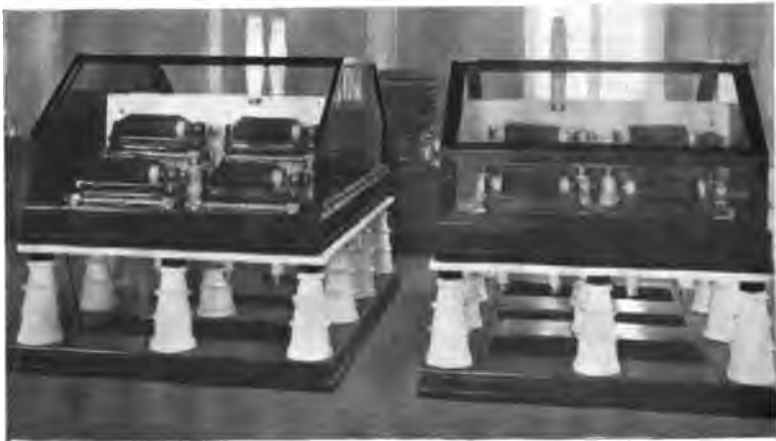


FIG. 152.—Spark gaps (Nauen).

[To face p. 297.]

The condenser battery D no longer consists of Leyden jars, which would have taken up too much space, but of a number of oil condensers in iron cases with high-tension leading-in terminals. These are connected partly in series and partly in parallel. Each condenser is equipped with an extra high-tension protective device and is provided with porcelain insulating feet. The separate condensers are built up to form one solid frame (Fig. 151).

The spark gaps are arranged on four stands in table form. Each stand contains eight frames of ten spark gaps in series. Each frame can be interchanged and replaced separately, so that new spark gap plates can be conveniently inserted.

The marble bed-plate of each stand is supported by means of twelve high porcelain insulators on a wooden base (Fig. 152). Ample provision is made for ventilating and cooling the spark gaps. Under each stand on the cellar level is a fan which forces the cool air towards the spark gaps and the hot air away, through special channels made of glass plates with a view to insulation.

The self-induction of the excitation circuit consists of several spirals of copper strip which together with the coupling and tuning coils of the aerial are mounted in three large insulated wooden frames (see Fig. 150). The wavelength can be varied in steps between 3000 and 7000 metres. In order to enable the change of wavelength to be effected as rapidly as possible the connections to the coils are changed by means of lever switches which are mounted in front of the coils on marble slabs and insulators. For each wavelength a set of these switches is provided by means of which the primary circuit is tuned and the coupling and adjustment of the aerial lengthening coils is effected. A finer adjustment can be effected by means of a limited movement of the coils, which are arranged so that they can be rotated relatively to one another. The connections between the separate parts of the transmitter consist of copper tubes, by which losses through "skin effects" are avoided. A connection leads from the coupling coils, through an ammeter to the central earthing point. Another connection goes from the tuning coils through an aerial transmitting and receiving switch to the antenna leading to the tower, to which the six leading-in insulators of the antenna are fixed.

Telegraphing is effected by means of four transmitting relays, A (Fig. 150) which interrupt the alternating current between the generator and the transformer. The relays are operated by a small key which works an intermediate relay.

Owing to the dimensions of the transmitter it was found impossible to provide for direct control and regulation of the separate pieces of apparatus, the more so as the necessary adjustments which have to be made while actually working would, owing to the extremely high pressures, have entailed considerable risk to the staff operating the station, if any slight mistake were to occur. For this reason the changing of wavelength, tuning, and the operation of all the regulating resistances and other adjustments are effected by indirect control from a central operating room.

This room may well be designated the brain of the station, as the engineer in charge can observe and operate from here all the necessary measuring instruments, fuses, and switches. The operating room is slightly raised, and its position has been chosen so that the transmitting room and also the machine room can be seen from here. Instructions are given by means of speaking tubes to the staff in the machine room and operating room.

The telegraphist no longer needs to exercise any supervision over the transmitter, owing to centralisation of the transmitting apparatus. His duties consist solely in transmitting and receiving the Morse signals. In order to entirely exclude all disturbing noises due to the machines and fans the receiving room is rendered sound-proof by means of double glass partitions and ceiling.

The receiving arrangement itself consists of a number of special pieces of apparatus which are specially designed for picking up signals over a wave range of from 300 to 10,000 metres wavelength. They are also provided with automatic transmitting and receiving blocking devices. The necessary apparatus for receiving undamped waves, and for receiving several telegrams from different stations at the same time, are so arranged that they are always ready for use and only need to be switched on or off. The Morse key for operating the transmitting relay is also in the telegraph room (Fig. 153).

When there is a considerable amount of telegraphic traffic to be dealt with, an automatic Wheatstone transmitter is used instead of the hand-operated Morse key. By this means the speed of telegraphy can be increased to three times that attainable by hand.

When these alterations had been completed, experiments in long range telegraphy were commenced. These experiments were at first conducted with only half the available transmitting



FIG. 153.—Operating room, Nauen.
a. Receiver.
b. Lieben valve and sound intensifier.

[To face p. 298.



power, in order that, by gradually increasing the power used to the maximum value, a series of comparative practical results could be recorded, which would clearly show the improvement on the previous arrangements. The experiments gave entirely satisfactory results.

Similar stations, installed for the German Government at Windhoek and Togo in Africa, were destroyed before their capture in the late war, and for the Japanese Government at Funi-bashi. During the late war, the spark apparatus just described was duplicated by an 800 kw. continuous wave transmitter, energy for which was provided by two Arco high-frequency machines. In 1919 a 10 kw. valve transmitter was also installed, particulars of both of which are better deferred to the chapter on continuous wave work.

TRANS-OCEANIC WIRELESS SCHEMES (Fig. 154).

At the end of the first decade of the present century, wireless telegraphy had proved its capabilities to maintain communication over long ranges of several thousand miles.

Whilst the installation of wireless stations offered lower initial and maintenance costs than submarine cable telegraphy, on the other hand, its dependence upon atmospheric conditions by no means showed that it would replace submarine cables, particularly since the later offered greater secrecy, a very important requirement in ordinary commercial work, where secrecy cannot be absolutely guaranteed, even with the use of an ordinary commercial code.

For strategic purposes, however, the advantages are manifest. In the event of war, messages can be transmitted to all vessels upon the high seas, so that merchant vessels can seek, if necessary, a neutral port or alter their course to avoid capture. Naval vessels can receive strategic orders, which otherwise they could not do, until their return to a port, which may, or may not, be friendly. Such advantages were impossible to obtain with submarine cables, which also suffered from the possibility of an hostile vessel cutting them, after possibly deriving information by their means.

Hence at the period already mentioned all civilised countries were considering the use of wireless stations, not only for the above purposes, but also as a means of linking up the mother country with its distant possessions.

WIRELESS TELEGRAPHY

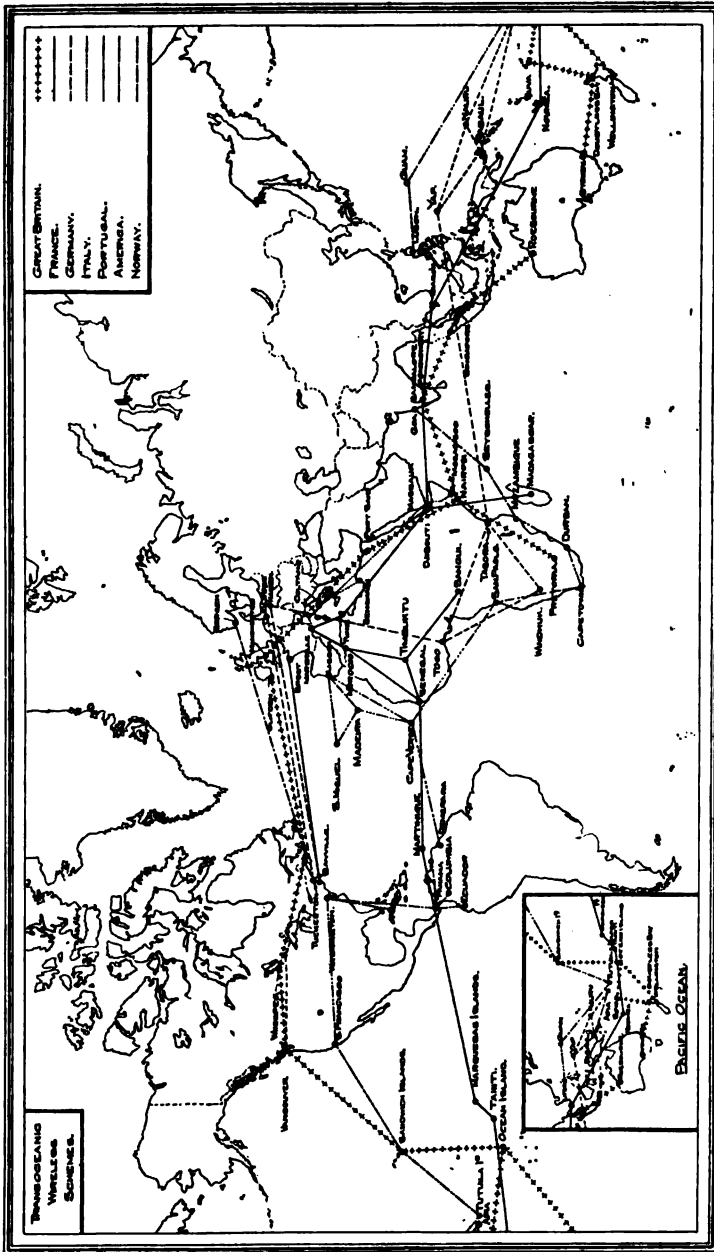


Fig. 154.—Trans-Oceanic wireless schemes.

In describing the various schemes for such connections, actually used and proposed, it will be most convenient to deal with them separately.

The British Scheme.—This was first brought into prominence in 1911 by the proposals of an Imperial Conference, which made recommendations on the above grounds, and proposed a complete girdle by which it would be possible to transmit messages completely round the World.

Unfortunately whilst England was first in the field in this connection, it is the only country which is now not in wireless communication with its colonies (if we except Germany, which was in 1914 in such communication, but has now lost her colonies).

The wireless girdle was to commence from England (Devizes) and to work with a station at Port Said, over a distance of 2200 miles, from whence connection was to be made over a like distance with Pretoria in South Africa, via Nairobi in British East Africa.

Nairobi would continue the girdle eastwards to Bangalore in India, from which station all British India would be able to receive intelligence from lower power commercial or military stations at Allahabad, Bombay, Calcutta, Karachi, Lahore, and Nagpur.

Bangalore would also make connection with Singapore over a distance of 1900 miles. This latter station was to work with a high-power station on the north-west coast of Australia, which would be in connection, possibly by wire, or otherwise by wireless to the Telefunken stations at Perth and Freemantle.

Australia and New Zealand is connected by the Perth station and another of several Telefunken stations in New Zealand, situated at Wellington.

This would be able to work with a proposed station at Ocean Island in the Pacific, distant 2800 miles, and also to the Sandwich Islands, and from thence, over 2700 miles, to Vancouver, and if necessary to the U.S.A., via an existing station at San Francisco.

Connection across Canada was practically assured, but it was proposed to erect an inland station at Winnipeg, which is 1300 miles from Vancouver and 2000 miles from the existing Marconi station at Glace Bay, then already working with Clifden in Ireland.

Whilst proposed in 1911, the only long-range stations of this scheme now existing are the Marconi stations at Glace Bay and Clifden, and the Telefunken stations at Perth, Freemantle, and Wellington, then about to be erected and since completed.

In 1912 a contract was made by the Government with the Marconi Company for the first five stations of the girdle mentioned. This contract eventually became the subject of a Royal Commission, and the whole discussion will probably be remembered.

On the outbreak of war in 1914, the erection of these stations was far from complete, and the British Government did not wish to proceed with them. In 1918 the contracting company was awarded the sum of £590,000 damages for the breaking of the contract, partly for work carried out, and partly for loss of expected royalties, a total claim of no less than £7,181,000 being made.

To inquire into wireless telegraphic research, and the best installation of a new Imperial Scheme, a Parliamentary Committee was appointed in 1918, under the presidency of Sir Henry Norman, M.P., one of the few men in Parliament, and possibly England, who was himself a scientific investigator having an international aspect of the subject.

Sir Henry Norman was one of the greatest critics of the original 1912 scheme. Possibly on these grounds, the managing director of the Marconi Company took the unprecedented step on the part of a Government contractor in protesting to the Prime Minister against the presence of Sir H. Norman on the Committee, a procedure which was resented by the other members of the Committee, composed of various Government officials and scientific advisers, who immediately, in the absence of the President, passed a resolution of confidence in its Chairman.

Obviously it is the purpose of the Parliamentary Committee to critically investigate all the technical possibilities of present and future wireless working, without binding themselves to any particular company, so that they are unable to install other newer apparatus and improvements, but so that they are able to install the best apparatus evolved by the collected progress of the world, paying, if necessary, reasonable royalties for patents, if their validity can be maintained, should the companies themselves refuse to contract at equitable rates.

The French Scheme.—The proceeding just mentioned is essentially that of the French Government, who have refused to give monopolies to any wireless companies, with a result that their naval and military stations have utilised all improvements and are perhaps second to none in all the world.

To such a great extent has wireless progress in the French army proceeded, that in continuous wave work, during the late

war, our Government found it advisable to adopt and copy the French army apparatus, a proceeding followed by other Allies and even by the Germans.

The wireless girdle proposed for France, many of which stations have been erected, took origin from the Eiffel Tower station in Paris which works with high-power stations at Brest on the western coast and Marseilles on the southern coast.

Marseilles then works with Tunis and thence to Somaliland over 2700 miles, then to Madagascar in the Indian Ocean, via Pondicherry in India (2500 miles) to Siagon in Cochin China (1850 miles).

The chain will be completed to Noumea (4700 miles) via a short range station at Iahite in the South Seas to the Marquesas Islands and then over the exceedingly long range of 5800 miles to Martinique in the Atlantic.

This station will be in touch with the station at Senegal (3000 miles) in French West Africa, and from thence will return via Morocco to Marseilles over distances of 1550 and 650 miles respectively.

Morocco will also serve to communicate with stations at Timbuctu in the Sahara Desert and Bangui in the Congo, over respective distances of 1250 and 1300 miles overland.

Should the remaining unbuilt stations required by this scheme be completed, France will possess two of the highest range stations in the world. She is able to work direct with the United States by means of the station on her western coast, and it is assumed that owing to her friendly relations with Britain she will be able to make use of the British stations if this should be required.

The German Scheme.—Owing to the different situations of the German colonies this was not a wireless girdle, but on the outbreak of hostilities in 1914, Germany, of all the Great Powers, was the only one which had a completed wireless scheme, part of which was of great use to her during a considerable period of the war, maintaining communication with the U.S.A., and part of which was, fortunately, by a series of brilliant strategical operations, either captured or destroyed.

The chief station was the Telefunken station at Nauen, which not only maintained direct communication over a distance of 3400 miles, all overland, largely tropical forests or deserts, and therefore the worst possible type of wireless range, but allowed her to communicate direct with Tabora in German East Africa which was 2400 miles overland from Togo and Windhoek in

German West Africa, which was 2300 miles overland distant from the same station. Such was the excess of power allowed that Nauen can be regularly received over the much greater distance to Australia, which is the longest range ever attained. Both Windhoek and Tabora were able to intercommunicate.

The German South Sea possessions were in possession of four stations at the corners of a parallelogram formed by Yap, Rabaul, Nauru, and Apia, the average range being 1800 miles. Communication with Germany from these stations was via the German-Holland cable at Yap, and they could also work with the British stations at Fiji and Australia.

Connection with the United States and Germany has been long possible between Nauen and Sayville, and just before the outbreak of war in 1914 was duplicated by the high-frequency machine stations of the Goldschmidt Company in Hanover and Tuckerton (New Jersey), both of which connections were very extensively utilised before the entrance of the U.S.A. into the war.

All these stations, other than the two Goldschmidt stations, were built by the Telefunken Company and a daughter company.

The fate of these stations during the war was as follows:—

The four stations at Yap, Nauru, Rabaul, and Apia were captured by the Australian Navy in August and September of 1914.

One of the most brilliant expeditions of the war led to the capture of Togo, but before its capture the station was blown up. Whilst nationally the destruction of this station is to be complimented, it is regrettable on purely technical grounds, since Togo was a replica of the Nauen station, with all the recent improvements and therefore possibly the best wireless station in the world, at this period.

The Windhoek station, which, with Tabora, remained in direct communication with Nauen, after the destruction of Togo, was captured by the equally brilliant campaign of General Botha early in the war. The German East African station, however, remained uncaptured for a very long time, owing to the stubborn resistance of this colony, which was the only German possession left until late in the war.

The Sayville and Tuckerton stations were taken over early in the war by the U.S.A. Government, since complaints were received from the Allies regarding their assisting German submarines by means of a code based on the spacing of dots and dashes. They maintained direct communication between the U.S.A. and Germany until the former entered into the war.

Russia.—Russia possessed a large number of high and medium-power stations, chiefly Telefunken, upon the shores of the Baltic, White and Black Seas.

A large station was also erected in Petrograd, which maintained, in the early days of the war, communication with Paris and via England, the United States. This station is now used for Bolshevik propaganda purposes.

• **The United States.**—A large station has been erected at San Francisco, which works with a similar station at Honolulu in the Sandwich Islands, and from thence Japan can be worked at Funibashi.

Communication with Europe was possible via Sayville, Tuckerton, and via Canada (Glace Bay) to Clifden. The Arlington station can also work with Cuba and the Panama Canal stations.

The American Navy Department in conjunction with several manufacturing companies obtained in 1915 a record with wireless telephony by working between Arlington (Virginia) and Mare Island (California) a distance of 2500 miles overland, and it was possible, by use of a wire telephone, to speak direct from New York to California. This range was largely experimental and far from commercial, but since then, wireless telephony has been carried on between Arlington and Eiffel Tower in Paris.

Holland.—According to the "Wireless World" of June, 1918, Holland has been able to directly connect with the Dutch East Indies by two high-power stations, over the enormous distance of 10,000 miles. According to the above journal these stations were erected by a Dutch engineer, Van der Groot, but according to the "Electrician" of Dec. 21st, 1917, the contract was obtained by the Telefunken Company.

Italy.—Has a number of low-power Marconi stations working with her North African possessions and high-power Marconi stations at Coltano and Messina, separated by 2800 miles.

Norway.—Maintains a long-range communication between Bergen and New York. A Telefunken high-frequency machine station at Övresaeter is to duplicate this.

Portugal.—Links up her possessions from Lisbon to Cape Verde and from thence to Demerara in South America and also to San Paulo in Portuguese West Africa. From the latter place, by use of the British stations at Capetown and Durban, she could work round South Africa to Mosambique, in Portuguese East Africa, and so, via Seychelles, to Goa in Portuguese India.

Japan.—Is well provided with ordinary coast stations. Before

the war a contract was placed with the Telefunken Company for an 100 kw. station, similar to Nauen, to be built at Funibashi. This station was completed in 1915 and can work with San Francisco by relaying at Honolulu. A further similar station is now being erected at Choshi to render the Japanese Dependency, Manchuria, independent of cables via her natural enemies, China and Russia.

Fig. 154 summarises the long-range stations mentioned.

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CHAPTER XI.

WIRELESS TELEGRAPHY IN WARFARE.

THE outstanding requirement of all military wireless apparatus, as distinct from marine and land station work, is that of portability. The degree of portability for different types of station must itself vary according to the arm of a military force with which the station has to work. Corresponding to this degree of portability, the range of the installation will vary; for example, it is obvious that whilst a slowly moving headquarters, secure from capture, can have a very powerful station transported by motor vehicles, such an installation must be replaced in an infantry unit, by a smaller installation which can, in common with all other infantry equipment, be carried in a knapsack.

It is interesting to consider how the development of transport has simultaneously permitted very great armies to be rapidly thrown into any present-day conflict and so created the need of more efficient means of communication, of which we may regard wireless telegraphy as being the most recent development.

If we consider a battle, such as that of Hastings or Agincourt, in relatively early history, when combat was of the hand-to-hand type, and the only means of transport was on foot we find these decisive battles were fought on a very small area, so small that no means of communication were necessary, since the commanders could themselves survey the entire field and issue orders, either by word of mouth, or by personal example.

Later, on the regular use of explosives, the area of battle became more extended, but, in comparison to modern warfare, was still negligible. For example, in the Napoleonic wars a single commander from an elevated position could still easily personally survey the entire battlefield, and maintain rapid communication with all parts of his forces by means of mounted aide-de-camps. The most rapid means of transport was still by horse, and fresh troops could not, unknown to the opposite army, be thrown rapidly into the field. Hence knowing the enemy's reserves within a day's march, other reserves could be neglected, since,

before their event on the actual field of battle, a decision would doubtless have been already obtained. Simultaneously, since transport was only by wagon the rapid concentration of supplies was impossible and a natural limit was set to the size of an army.

The growth of rapid transport, as by rail in the middle of the nineteenth century, led to the more easy concentration of men and supplies. Hence in the Franco-Prussian War of 1871, we first obtain an example of modern warfare, where the combatants were numbered by millions. This growth in numbers removed the possibility of a single commander being able to survey simultaneously the whole battle front. To maintain the necessary communication with subordinate commanders, the advent of the electric telegraph was soon to provide a means.

The installation of such line telegraphy was, however, dependent upon friendly relations with the inhabitants. Where this was not possible, as in our own warfare in India and other tropical countries, a further means of communication was obtained by use of helios, i.e. the transmission of Morse messages by the reflection of the sun from a mirror. At this period, as in the Boer War, the Russo-Japanese War, etc., means of transport had so rapidly developed, by rail, cycles, and later motor vehicles, that a commander had to take into consideration the presence of enemy troops, which a century before he could have, for the moment, entirely neglected, but now, in the event of an engagement, could be rapidly brought up and thrown into the field against him.

The needs of communication were now exceeding the possibilities of line telegraphy, since this necessitated the transport of much material, considerable personnel and time to lay lines. These might be hundreds of miles in length, and after they were laid, necessitated the withdrawal of a very considerable portion of the force from the fighting line, to maintain and guard such lines.

To overcome this objection to line telegraphy, necessitating a long line for very little traffic, the advent of wireless telegraphy in the latter half of the last decade of the nineteenth century was utilised.

The first to utilise such means were the Germans, to whom the application of all scientific progress to the needs of their theoretically "model" army had become a national mania. Before the dawn of the present century, the Braun-Siemens Company had supplied very many portable installations to the

German Army. The first actual use of wireless in warfare would appear to be in the China Expeditionary Force of 1900, where it was used in order to maintain communication between the land and sea forces.

It was first used by the British Army in 1902 and was also used by both sides in the Russo-Japanese War in 1906.

Up to this time the use could only be said to be experimental, since the whole technology of wireless telegraphy was itself in a developmental state. The German West African Herero Campaign first demonstrated the actual capabilities of wireless for military purposes, and the first extensive application was foreshadowed in the Turko-Balkan War, and later the Italian-Tripoli Campaign.

Portable stations have, however, found employment for more pacific purposes such as for exploration. By means of such stations expeditions are able to keep in touch with civilisation by means of existing or specially erected land stations. For example in the Mawson Antarctic Expedition, communication was maintained from the winter base on Macquarie Island to Australia, by means of Telefunken stations. Since this expedition, all exploratory expeditions of any importance have utilised wireless telegraphy to maintain communication with the outside world.

In the recent war the combatants employed wireless telegraphy to the fullest extent.

The results of such use are chiefly as follows:—

1. The establishment of the utility of the larger military stations, in order to conduct warfare over extended areas either on sea or land. Experience has shown, that unless (by regular espionage means of the intelligence corps) the enemy code has been obtained, there is little possibility of obtaining actual information by the interception of messages. Also messages cannot be effectually jammed. Nevertheless, the use of land lines, already largely existent on the Western Front, offered such advantages, by withholding of information regarding actual relative traffic in different sectors, that where possible, land line working from headquarters to behind the actual trench system was to be preferred to wireless working.

Such a preference does not hold good in operations in a more uncivilised region, as in the many subsidiary colonial wars in Asia, Africa, etc., and here the employment of larger wireless stations was very extensive.

For example, during the siege of Kut, by means of wireless the besieged force was able, right up to the time of its surrender,

to keep in communication with the force attempting its relief, a proceeding quite different from the siege of Lucknow, where the only information regarding the relieving force was obtained by means of native spies, often unreliable.

Wireless telegraphy was also greatly used in the conquest of German East Africa, where a very elaborate wireless system was installed, since permanent lines were obviously impossible to lay and maintain.

2. The employment of small installations to maintain communication between the actual front line and the reserve line. This necessity has arisen owing to the development of the modern artillery barrage. This, if intense, absolutely prevents any rapid communication across the barrage except by wireless means. For example, in 1916 the author was at the Vimy Ridge, which was in communication with the brigade headquarters by no less than five separate lines, buried about eight feet below the surface of the ground. When it is stated that the German barrage destroyed all five lines, within twenty minutes of the commencement of an attack, it can be realised how hopeless line communication across a barrage is, particularly when it is mentioned that towards the end of the war, even the barrage just mentioned had become of small intensity as compared with that used by both sides at, say, the Passchendaele Battle in 1918.

3. The use of direction-finders. These have as their objective, not the obtainance of actual intelligence, but the determination of the position of an enemy's wireless stations, with the object of ascertaining the location of his headquarters, and by subsequent observation of the volume of wireless traffic, the possibility of intended tactical movements.

Also such located headquarters could then be dealt with by artillery and aeroplanes. For example, the knowledge of the establishment of a large wireless station near Bruges, was of assistance in determining that Gothas raiding England set out from this location, which was then continually raided by our own machines.

Such direction-finders received their greatest use in the past war, in order to locate and keep track of the movement of enemy air-vessels, such as Zeppelins, during their raids on England, and to keep track of the movements of the enemy fleet and submarines.

4. A reversal to the earth induction method of Preece and Kiebnitz in order to maintain communication across a barrage zone. The development of the thermionic valve had made

detection much more sensitive, so that this method was greatly improved. Such a method had, in common with ordinary wireless, obvious advantages already mentioned over land buzzer lines, and for short distances had the advantage over ordinary wireless that it did not require the erection of a wireless aerial above the parapet with obvious objections, particularly from the point of view of the wireless personnel.

5. The use of an earth induction receiver system in order to intercept messages sent along enemy buzzer lines, employing the earth return system. It is to be regretted that the German Army was first in the field in this direction, and obtained much information regarding forthcoming tactical operations such as trench raids, etc. The exact knowledge of forthcoming events in the earlier days of the war, in spite of assumed absolute secrecy, was so great as to appear absolutely mysterious. It was only after the accidental capture by the French Army of such a German interception set, that the Allied Armies became aware of such means for obtaining intelligence.

Similar means were rapidly adopted by the French Army Wireless Service, who first supplied our own Army with intercepting apparatus. Unfortunately the German had already guarded himself against being hoisted by his own petard, by making all his front trench buzzer lines with a metallic, instead of an earth return, and also reducing all such front line work to the absolute minimum.

Nevertheless, such installations gave useful results by allowing us to check the unauthorised or foolish use of our own lines likely to assist the enemy. The reception of enemy messages by this means varied greatly. For example, the author in the Loos salient in 1916, where the front line trenches were often not more than five yards apart, in spite of laying earth wires of various types in various locations could never get any results worthy of the trouble and danger. On the other hand, the author's friend of pre-France days, Captain Bryden, R.E., who had a reputation for such work, was able in the Arras salient to obtain so much information, that he generally knew the exact composition of the German infantry rations opposite him.

Captain Bryden informed the author that the whole success was largely a matter of luck, i.e. he would lay several line systems with absolutely no result and then would unexpectedly, with a fresh line, obtain great success.

In this connection the author attempted to obtain results by using as earth lines the railway between Grenay (near Bethune)

and Cité Jeanne d'Arc in the enemy lines, and the branch railway to Cité Colonné. These formed two branching metallic conductors roughly a thousand yards apart in the enemy lines which were connected in our own lines by a cable through a three-valve intensifier of the French type. Unfortunately other than our own messages, no results were obtained as regards German messages, doubtless owing to their own general precautions.

Summary of Technical Developments During the War.

—On the outbreak of war the spark transmitter had proved its superiority, especially for portable installations, over the arc method of generation. Whilst progress was being made with both the Goldschmidt and the Arco high-frequency machines, their application was obviously only for large land stations and not for portable stations.

On the receiving side the crystal was, and perhaps still is, the best type of detector for all-round work.

Technical progress during the war was largely the adaptation of the thermionic valve to give more sensitive receivers for special purposes, such as direction-finding work and earth-induction interception methods.

Meissner's work, resulting in the possibility of using the thermionic valve for transmitting continuous wave oscillations, both for telegraphy and telephony, was generally known, and work was being carried out by many investigators to evolve a small transmitter dependent on valves. In this direction our own Army Signal Service was towards the end of the war making great strides, as was also our Air Force.

The earlier period of Army wireless was very unsatisfactory, and there were few officers in the British Army having more than an amateur knowledge of wireless telegraphy.

Wireless communication in the British Army was practically non-existent. A number of military portable stations were included upon the Signal Service Establishment, but, unlike in our Navy, no attempt had been made to test various types of transmitters and receivers, and to adapt them to the special needs of the Army. It is true that some years before a number of open-spark Braun-Siemens' stations had been purchased by the War Office, but since these offered little, if any advantages over other open-spark systems (unlike the later developed Quenched-Gap stations), the whole policy afterwards would appear to have been to dispense with any critical technical staff and to rely entirely upon the manufacturers of the very few stations our Army possessed.

On the outbreak of war our War Office technical staff would appear to have been entirely ignorant of later technical developments, and one can only say with regret, that in the first two years of the war, our wireless service was undoubtedly far behind that, not only of our enemies, but also of our Allies the French. Towards the later half of the war the growth of a wireless staff independent of commercial connections was however felt, and particularly in trench continuous-wave sets (using the French valve), our wireless equipment was attaining the desired technical standing.

It is noticeable that the larger spark stations built towards the end of the war, whilst composite, employed actual Siemens' Quenched Gaps. A type of receiver, which may be seen illustrated in Army Signals Experimental Establishment, Pamphlet 14 (W/T sets field, 120 watt C.W.), and practically identical with the Siemens' Universal Receiver E. 5, was also evolved.

In this respect it may be mentioned that our War Office apparatus is now composite, i.e. whilst the Siemens' Quenched Gap and Universal Receiver are used, the 500 cycle machine is manufactured by the B.T.H. Company and other parts by other companies. Hence whilst statements are often made which, on first sight, would appear to show that a single company is responsible for the British Army installations, a careful inspection will show that the sole statement is that various types of stations are manufactured by this company for general sale to the British, or any other army, who may desire such installations.

One may nearly say that all modern army stations are built upon the Quenched-Spark system when spark transmitters are used, but in the British Army the tendency is towards continuous-wave sets, largely due to the Signals Experimental Establishment at Woolwich, and which utilise the "French valve".

One may safely state that in the region of spark sets, with the exception of the adoption of the Quenched Gap by the British Army which had, however, been adopted by practically every other country before the war, no great advance has been made, except in small details of design, during the past few years.

The advantages of such a spark gap for portable stations are at once evident, since for any available primary source of electrical power, necessitating the transport of a certain weight of plant, twice the amount of energy is radiated by a Quenched-Spark Gap as by an open-spark gap, or, for equal radiative powers, a station upon the Quenched-Spark system will, in comparison to one upon the open-spark system, only require a generating plant

of half the output and much less weight, irrespective of the greater penetrative powers and freedom from jamming of the Quenched-Spark musical note as compared to the non-musical note, and the greater sharpness of tuning which is permissible.

Since it would be, for obvious reasons, impossible to illustrate the present chapter throughout with actual Army apparatus, most of which has come within the author's practical experience, the author makes no apology for illustrating it by actual Telefunken apparatus, since (1) by the employment of the Quenched Gap these stations have double the efficiency of other commercial types of military stations employing an open gap, or the modification which permits of the use of a musical note without quenching; (2) they are more akin to the present Quenched Gap British Army stations than Non-Quenched Gap stations, and lastly, they have not been previously illustrated in England, and the illustrations will therefore provide a variation of the usual types of military stations to be found in most English wireless books.

Advantages of Wireless Telegraphy over Land Lines in Warfare.—These may be briefly summarised as follows:—

1. Communication can be established between two points without the necessity of the intervening country being in friendly possession. Hence wireless is of great use to an entirely surrounded force.

2. Communications can be simultaneously sent to any number of different stations within the wireless range. If these are in possession of the code, they can by intercepting friendly messages, adjust their own tactical operations with full knowledge of the tactical movements of other allied forces. With land lines this result could only be obtained with a multiplicity of separate lines with consequent expense and upkeep.

3. Communication can be established between land and sea forces, in operations such as occurred at Gallipoli.

4. The cost of two wireless stations is much cheaper than a long intervening land line, the personnel for both wireless stations is negligible in comparison to the personnel required to lay, maintain, and defend a long land line.

5. The wireless station can be erected within 10 to 20 minutes and can so keep up with the troops taking part in an advance, whereas a much longer time is needed to lay even a temporary land line.

The chief necessities in the design and construction of portable wireless stations are those of light weight, quick installation

and great strength of construction, since the apparatus experiences constant jolting during its passage over rough country, sufficient to loosen and shake off nuts, etc., unless these are soldered or pinned.

The permissible methods of transport, disregarding stations for aircraft and railway vehicles, are :—

1. Conveyance by men, in knapsacks or cases. This does not permit of the use of a very large station, but is of very great use for scouting (and exploration purposes), permitting scouts to transmit intelligence to the advance guard at longer ranges and with less fear of detection than if heliographs were used. Such stations can be used over the roughest country if this permits the passage of men on foot.

2. Conveyance upon horseback or by mules. This permits a longer range to be obtained than by human transport, and rough country can still be traversed.

3. Conveyance by limber wagons. Very serviceable long-range stations can so be transported over comparatively rough country, but not over rocky country, etc. This type of station is therefore more confined to use with large bodies of the fighting force.

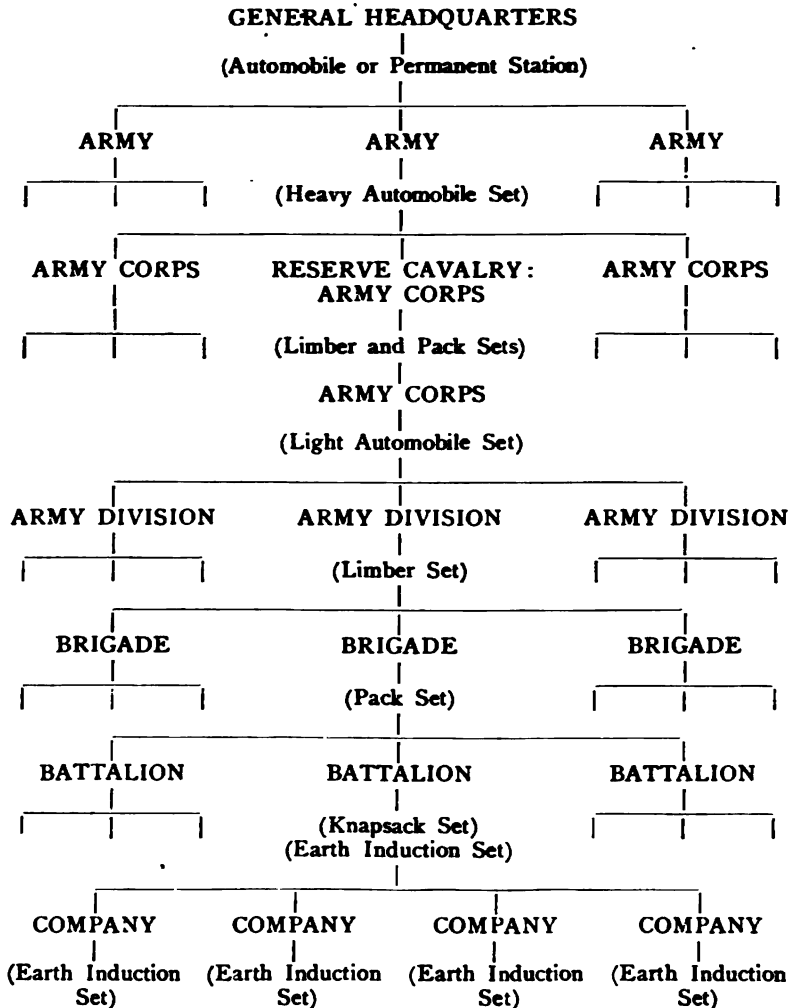
4. Conveyance by motor car. This necessitates fairly easy roads, and the stations, which can have very long ranges approaching those of fixed land stations, are confined to the headquarters of the force, being used for transmission to outlying units or from army to army.

A list of standard stations with wavelengths and normal ranges is given in the following table :—

Type of Station.	Energy Radiated. (Kw.)	Fixed Wavelengths. (Metres.)	Range (over Flat Land).		
			By Day, Miles.	By Night, Miles.	
Aircraft {	Balloon	0.03	300, 450, 600	15	30
	Aeroplane	0.10	450, 600	60	120.
	Small airship	0.10	450, 600	60	120
	Large "	0.20	600, 900, 1200	150	250
Knapsack set	0.04	300, 450	15	25	
Packsaddle	0.30	450, 600, 900	45-60	80	
Landing	0.30	450, 600, 900	45-60	80	
Light limber wagon	0.50	450, 600, 900, 1200	100	150	
Heavy " "	1.50	600, 900, 1200, 1500	150	220	
Light automobile	0.50	450, 600, 900, 1200	100	150	
Medium " "	1.50	600, 900, 1200, 1500	150	220	
Heavy " "	2.50	600, 900, 1200, 1500, 1800	250	375	

The stations for aircraft necessitate special features and are dealt with elsewhere. In this chapter each class of the ground stations will be dealt with in detail.

As regards the employment of these various types of stations with the various branches of a modern army an hypothetical arrangement would be as follows :—



It must, however, be borne in mind that such an arrangement is ideal and the ideal is rarely experienced in actual warfare.

To take the Western Front, there was no need whatever for any stations behind corps headquarters, since the French civil telegraphs and special permanent lines were available, offering capabilities for much greater volume of traffic and more absolute secrecy. On the other hand, the exigencies of the service may require much greater stations than knapsack sets in the actual front line. For example, whilst the present writer was responsible for the inception and maintenance of wireless communications for the 1st Army Corps, B.E.F., the front of this corps in 1916 included the then hotly contested Loos salient. The town of Loos was nearly completely surrounded and, before very strong defensives were completed, always in danger of being completely cut off. For this reason a pack set installation was installed beneath the Brewery at Loos where the battalion headquarters of the garrison was situated, in order, in the event of Loos being surrounded, to maintain certain communication with the brigade headquarters at Les Brebis, although the actual distance between was only about 3000 yards.

Aerial and Counterpoise Arrangement for Military Stations.—In the earliest stations of the Braun-Siemens Company, the aerial was obtained without the use of a mast, by means of a comparatively small captive balloon which supported the aerial wire. The disadvantages of transport of such a balloon arrangement and its dependence on the supply of some gas is apparent, also its capabilities of betraying the location of the station to the enemy. Moreover, since its movements caused variation of the aerial height, and electrical capacity, the aerial wavelength varied greatly, although at this period wireless stations were, in general, not so sharply tuned as later in wireless history.

No earth was used in these earliest military stations, but a counterpoise, formed by the use of large tinfoil cylinders, having a large capacity, but simultaneously offering great difficulties of transport.

Nowadays masts have replaced the balloon method of obtaining an aerial. These take two forms :—

1. A telescopic "comet" mast.—This consists of steel tubes which telescope within each other and with the larger stations are carried fixed to a limber wagon. A winch upon the wagon raises these tubes section by section, the innermost first carrying the aerial block and halyard. On being wound upwards by the winch to its full extent the innermost section is then locked in position by a pin to the following sections, the process being repeated for each section in order. Such a small telescopic

mast is shown in Fig. 155 *a* and *b*. The objection to this form of mast is that, in actual practice, when any considerable height is to be obtained, the whole structure is "wobbly" even with the best fitting masts. Whilst this defect is partly overcome by the use of stays, and, providing the height is obtained, it is immaterial whether the mast is kinked, the whole effect is not pleasing.

Moreover, the winch requires a separate wagon for its transport, and with this type of mast, if one section becomes accidentally damaged by a fall, the whole mast is put out of action

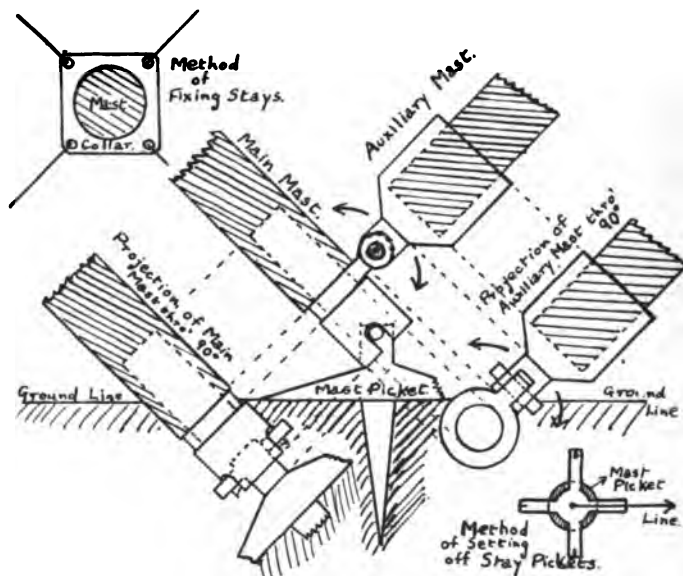


FIG. 156.

since it will not then telescope, or some time must elapse in order to replace the damaged section.

Nowadays the tendency is to build the mast in sections about 3 metres long of some light aluminium alloy as "duralumin". Each section is interchangeable, one end being slightly tapered to fit into the previous section and one end slightly expanded to receive the next section.

These sections are built up on the ground to the desired length, and at intervals metal collars are fitted to which three sets of four stays are attached (Fig. 156).

These stays are taken to four steel pickets about 4 feet in length which are driven into the ground at equal distances from



FIG. 155 a.—Military
"Comet" mast.

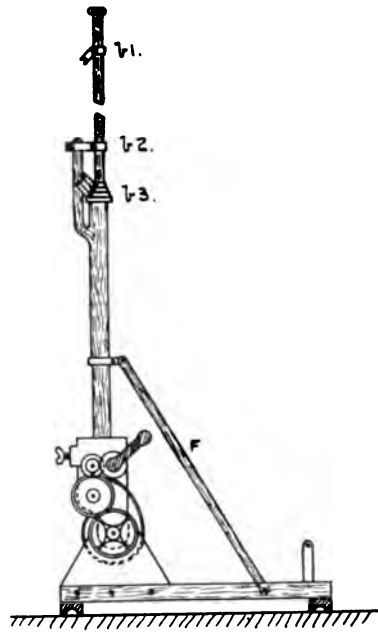


FIG. 155 b.
[To face p. 328.]

4

the mast foot. To avoid confusion, each set of four stays are painted differently.

The foot of the mast, i.e. its lowest section, fits into a shoe having two diametrically placed recesses, engaging with similarly placed stout pins upon a special metal picket. The shoe also carries a socket for a mast section, rotatable around its long axis at right angles to the mast direction before it is raised. From this shoe socket a smaller auxiliary mast of about three or four sections is built up, which can easily be raised by two men with a tackle working upon the picket opposite to the auxiliary mast's direction.

This auxiliary mast is so raised, and when vertical it is fixed by means of tackle so that relative movement to the main mast to which it is now vertically at right angles is prevented. Its highest extremity carries the shackles of one set of three stays and a block having a tackle to the picket directly opposite to the main mast's direction. By means of this tackle and the leverage furnished by the auxiliary mast, two, or at the most three men can easily raise the main mast of 80 to 100 metres height.

To ensure this being done without risk of its being raised past the vertical line, one man is stationed at each of the three pickets, and tightens or slackens any of his three stays according to the command of the officer or N.C.O. in charge of the operation. As soon as the mast is vertical the stays used to raise the masts are fixed to the correct picket.

To erect such a mast of 100 feet height only five men are necessary, and the whole operation, facilitated by repeated drills, can be entirely completed in about ten minutes. The chief art is the rapid and correct laying out, in the prone position, of the various stays, so that the set which are to stay main and auxiliary masts together are above the corresponding set to the picket on the same side of the main mast. Also correct and accurate laying off of the pickets from the foot of the mast is necessary. This is done by use of a small metal right-angle cross, known as a "peg-marker," which is fitted upon the centre of the mast picket. Connected to the centre of this cross is a line of correct length, which is consecutively carried outwards in the centre of each of the four arms of the cross.

It is by a similar method, but using more rigid auxiliary masts and stone piers, instead of pickets utilising the Telefunken ball and socket joint, and repeating the operation, that the much heavier permanent steel masts of 100 metres or more are raised at land stations (see Chapter X., Fig. 134).

The operation for the lowering of the mast is exactly the reverse to that for erection.

To promote quickness in erection and to prevent the stays from kinking, the stays are carried on correctly marked drums with a ratchet for winding them up. To unroll them the free end is fitted to a picket, and the wire is, without any fear of entanglement, unwound by merely walking away from the picket to the mast collar after the ratchet pawl is released.

This type of mast is just as quick and more easy to erect than the telescope form, and has the advantage of being a more rigid mast, all parts of which are interchangeable.

The aerial may be a T or L aerial when two masts are simultaneously erected, or an umbrella aerial necessitating only one mast.

With military stations, except when they are built up for more or less permanent work, no attempt is made to obtain an earth, which would involve great labour and loss of time perhaps, in unfavourable spots, without result.

A counterpoise is often used as with land stations, by means of a system of wires supported by the mast or masts at a height of about 7 feet, i.e. just sufficient to prevent a man from striking them with injury to himself and them.

The British Army stations usually make use of "earth mats" either with or without a counterpoise of wires. These consist of copper gauze rolls about 1 yard wide and 10 yards long, connected together and to the earth terminal of the wireless station and just unrolled out upon the ground. If the location is dry, they doubtless act as a counterpoise chiefly by capacity effects, whereas if the location is damp (they are preferable intentionally made wet by pouring water on them) they act as a true earth.

This gives a rapid means of "earthing" together with an earth of constant properties.

The number of such earth mats may vary, and they are usually arranged symmetrically around the wireless stations. If only one is available or otherwise, propagation of the aerial radiations is generally said to be best, when the direction of the earth mat is opposite to that of the receiving station. Whether this may be so or not, the author always preferred, if time permitted, to vary their positions until the greatest aerial current reading was obtained, the difference in aerial readings being very appreciable, and maximum reading showing the most advantageous mutual relation of aerial and earth mat capacities.



FIG. 157 *a*.—Generating plant of knapsack set (assembled).



FIG. 157 *b*.—Generating plant of knapsack set (packed for transport).
[See p. 321.]

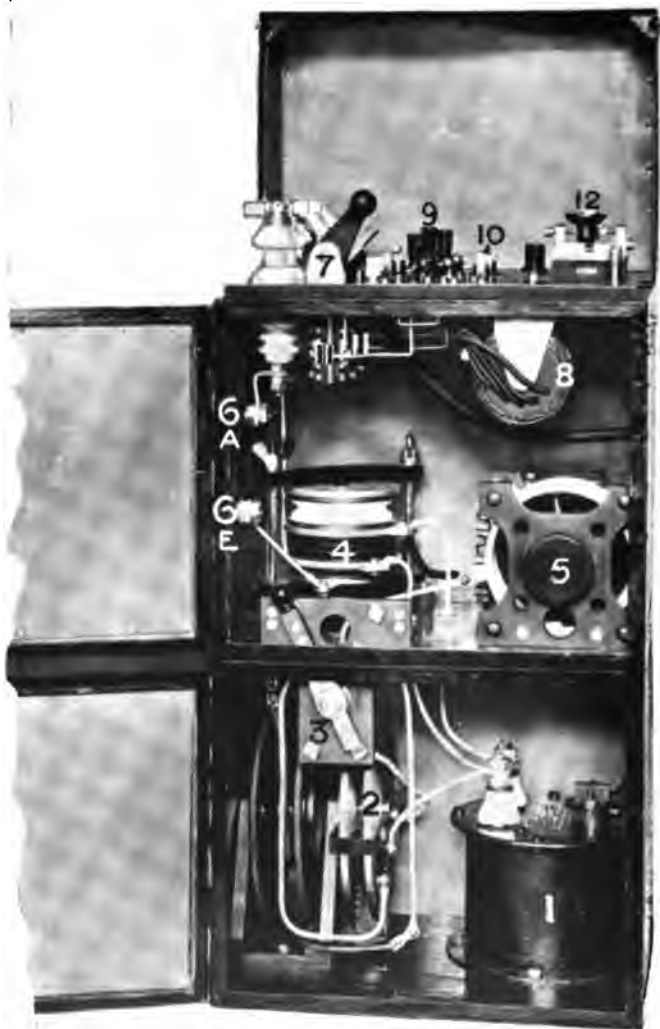


FIG. 157 c.—Wireless apparatus of knapsack set (receiver and transmitter.)
[To face p. 321.]

The Knapsack Station.—This form of station is, as already mentioned, designed for the use of infantry scouting and reconnoitring parties so that they may keep in touch with the main body of the army, and, in modern warfare, for use in trenches. For such purposes the station must be exceedingly compact and light, but capable of quick assembly. The portions carried by each man should not exceed the weight of the normal military knapsack, i.e. it is about 60 lbs. per man. This is obtained by dividing the complete station between four men as follows:—

One man carries the source of current, i.e. the generating plant.

One man carries the wireless transmitter and receiver, i.e. the wireless apparatus proper.

The remaining two men each carry one mast and part of the aerial and counterpoise.

The chief difficulty encountered in the design is the source of power. Accumulators, owing to their comparatively heavy weight, are always a source of trouble to recharge, etc., although often used. A small magneto dynamo giving current at 500 cycles is preferably used as with this installation. This is actuated by means of a gearing upon a stand shown in Fig. 157 *a*, the generator G, seen at the bottom, having a small tachometer T to control its speed. This gearing is worked by hand by two men and does not greatly tax their powers. When being transported it is totally enclosed in a knapsack as shown in Fig. 157 *b*. In the earlier experiments instead of a hand gearing a tandem bicycle frame was carried and the generator driven by two men pedalling.

The actual wireless apparatus is carried in a knapsack by the second man. The case containing it opens at the top and in the front. For convenience of adjustment all the necessary switches for operation are mounted within the top cover, so that the case itself forms a very convenient desk and need not be open in front.

The current derived from the dynamo is stepped up to the necessary high tension by means of the transformer, 1 (Fig. 157 *c*), and feeds an excitation circuit consisting of an inductance, 2, mica condensers, 3, and spark gap, 4. The aerial circuit includes an aerial variometer, 5, and to indicate resonance a removable hot-wire ammeter, mounted outside the case upon the left-hand side is connected to the aerial at the terminal δ_A and to the counterpoise, by terminal δ_B .

Upon the top of the case is mounted a change-over switch, 7. The receiver consists of the receiving transformer, 8, upon which

tappings are taken by means of the plugs, 9. The detector is placed in the sockets, 10, and the telephone, shunted across the fixed condenser, 11, is plugged into sockets upon the top of the case. The Morse key, 12, interrupts the low-tension primary circuit. The fixed wavelengths for the transmitter are 300 and 450 metres, reception being obtained between the range of 250 to 1200 metres.

For radiating the energy, a T or L aerial is used stretched between two 30 feet telescopic masts of steel tubing. These masts may be packed in 5 feet lengths and they weigh 20 lbs.

Each mast is supported by four stays and can be erected in one piece, the counterpoise being stretched between the lower parts. The whole station can be erected by four or five men in 10-15 minutes, and then requires two men to actuate the dynamo and one to carry out the telegraphic work. The guaranteed range is about fifteen miles by day overland.

The Packsaddle Station.—This form of station is for the use of cavalry parties, and is transported upon the backs of horses or mules, the majority of the apparatus being so designed that it is transported in an assembled condition and only requires the particular units to be connected up to each other.

The subdivision of the station is similar to that of the knapsack sets, one unit carrying the current generating plant, weighing 175 lbs., one unit the telegraphic apparatus, weighing 165 lbs., and two units each carrying a telescopic mast and aerial or counterpoise material of about equal loads. If possible a further pack is transported carrying tools, spares, and fuel.

The generating plant (Fig. 158 *a*) consists of a 3 h.p. petrol motor, mounted upon a common frame with a 500 period alternating-current generator. The petrol motor is started by means of hand gearing and requires $2\frac{1}{2}$ quarts of petrol for three hours' operation, a total supply for twenty-four hours being carried.

Occasionally this petrol engine is replaced by a tandem cycle frame, so that two men can drive the generator by means of pedal gearing.

The alternating-current generator is excited by a direct coupled small continuous-current dynamo and works at a normal speed of 4500 revolutions per minute under the control of a tachometer. It delivers from 0.4 to 0.6 kw. at 220 volts. When being transported the frame is divided into two halves, one of which goes at each side of the animal (Fig. 158*a*), fitting directly upon a packsaddle and being covered for protection.

The telegraphic apparatus is all transported in two leather

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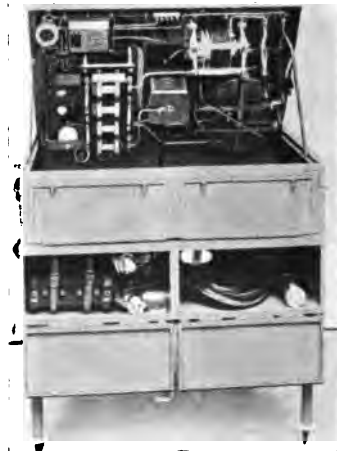
a. Generating plant (packed).



b. Mast and accessories (packed).



c. Wireless plant (ready for use).



d. Wireless plant (showing interior of case).

FIG. 158.—Pack station.

[To face p. 323.]



cases, each slung similarly upon one side of the second pack animal, and when in use these cases fit together and form, by means of folding legs, an operating table, as shown in figures 158 *c* and 158 *d*. In the first illustration may be seen all the apparatus, such as the receiver transformer, detector, Morse key, aerial ammeter and variometer, which are placed upon the outside at the top.

Within the cases and accessible by means of flaps or by raising the table top, Fig. 158 *d*, is the transmitter excitation circuit consisting of a 7-part spark gap, four paper condensers having a total capacity of 10,000 cm. and flat primary inductance, together with other apparatus, such as a resistance for adjusting the current used, transformer and receiver tuning condenser, the handle of which projects through the table.

Transmission takes place upon the 450, 600, or 900, metre waves by change of plugs and sockets and reception throughout the range of 250 to 2500 metres.

The apparatus is protected from the weather by means of a canvas cover, and when used for a prolonged period, by means of a tent, which is lighted at night by transported acetylene lamps. Two masts are used carrying a three-wire T or L aerial and, at a distance of a few feet above ground, the counterpoise. This form of aerial permits the station to be used, if necessary in a narrow ravine or street. The masts have a total height of 45 feet, and each is capable of telescoping into two halves about 5 feet in length which are carried on the flanks of the pack animals, as in Fig. 158 *b*.

Six men are required to erect the station, the time occupied being fifteen minutes, after which two men can operate it.

The range obtained is about sixty miles by day or eighty miles by night over flat land, with not more than 25 per cent. wooded land.

The Landing Station.—This is very similar to the pack-saddle station in design, but is all transported in two cases, each of which may be carried by two men or upon a light trek cart.

It is designed to permit naval landing parties to keep in touch with their vessels during an expedition, and was the kind of wireless station first used for active military purposes in China.

The energy radiated is 0.3 kw. as in the case of the pack-saddle station, but a longer range is obtained if used over water.

This type of station, transported in a light trek cart, tends to replace the pack form. In actual practice with a pack set it is found difficult to reduce the generating plant below a weight of

about 160 lbs. It is impossible to subdivide this between two pack animals, since neither animal's paniers are then balanced.

Whilst a pack animal can carry the generating plant, the load is so heavy that it is soon exhausted, unless this heavy load is repeatedly, but inconveniently, shared periodically amongst the four pack animals. The author had a Marconi pack section of this type (where the loads are approximately similar to those mentioned), under his charge in France, and, in common with all similar stations in the Army, the pack method of transport had been superseded in favour of a light trek cart, which transported the whole station. Whilst such a cart somewhat restricted the portability over rough country it overcame the difficulty of the heavy generating-plant load, which would in practice have also restricted any considerable day's march, with packsaddle transport.

The Limber Wagon Stations.—Limber wagon stations are intended for use with the heavier divisions of an army, such as artillery batteries. There are two standard stations, one of which is transported by one double limber wagon and obtains a range of 100 miles by day and 150 miles by night, with 0.5 kw. of radiated energy, and the other, with triple this radiative power, is transported upon two double limber wagons, one of which is seen in Fig. 159. It has a range of 150 miles by day and 220 miles by night.

A detailed description of the larger station only will be given since, except for differences of outputs, the stations are practically identical.

In this station the generating plant consists of a 4-6 h.p. single cylinder petrol engine with Bosch magneto-ignition, automatic lubrication, and water-cooled by a honeycomb cooler and belt-driven fan.

The petrol is supplied from a tank above the engine, holding a twenty-four hours' supply, no extra feed pressure being required. Regulation of the speed by the supply both of petrol and air is effected by means of a common handle, which varies the speed from 1000 to 2000 revolutions per minute (Fig. 159 *b*).

A 2.5 kw. alternating-current generator is direct-coupled to the above motor, and delivers power at a pressure variable between 70 to 110 volts. Excitation of this generator is obtained by a small direct-coupled continuous-current generator seen in front of the alternator in Fig. 159 *a*, which also supplies the current for illumination.

A marble switchboard is mounted beside the engine, Fig. 159 *b*.



a. Generating plant wagon (alternator side).

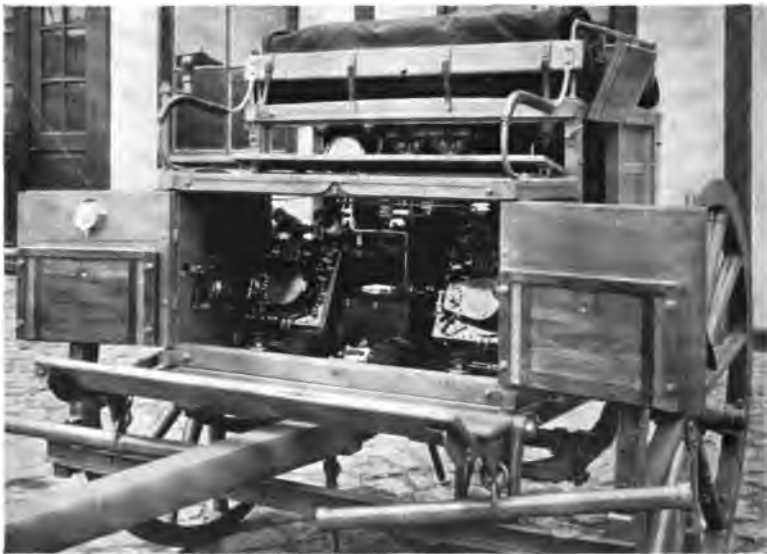


b. Generating plant wagon (engine side).
FIG. 159.—Limber wagon set.

[To face p. 324.]



c. Apparatus wagon (transmitting side).



d. Apparatus wagon (receiver side).
FIG. 159.—Limber wagon set.

[See pp. 325-326.]

On this board are mounted a double-pole double-throw switch, double-poles fuses, an incandescent lamp, and a plug socket, intended for connecting a lamp for lighting the station.

Figs. 159 *a* and *b* show this generating plant, the petrol motor being visible from the one side of the limber and the generator with the D.C. exciter and protective high-frequency devices from the other side.

In the engine limber there are also two boxes for tools and spare parts, a plug socket for the main cable, the starting handle of the engine, a lantern and various accessories as oilcans, etc. Four seats are provided on the rear (engine) limber. When unlimbered four supports are used to steady it.

In the telegraphic apparatus wagon the various parts are arranged so that all the transmitting apparatus is on one side of the limber, Fig. 159 *c*, and can be attended to and adjusted from there, and all the receiving apparatus is on the other side. This arrangement renders the apparatus much simpler and more convenient.

The regulating resistances, for adjusting the pressure of the continuous-current dynamo, and thereby also the periodicity of the alternating-current machine and the pitch of the transmitted note, is connected with the power wagon by means of two connections and a multiple cable. In the connection to the transformer are inserted a switch and two current cut-outs, the latter being situated on the receiver to prevent any possibility of accidental transmission of signals during reception.

The alternating current at a frequency of 500 is transformed from about 100 volts to about 5000 volts. A primary iron-core choking-coil is connected in series with the transformer, serving to obtain resonance between the generator and the excitation circuit and to ensure equal loading of the machine. An A.C. voltmeter and ammeter seen in the top left-hand corner is fitted in the low-tension alternating-current circuit for its control.

The high-tension alternating current charges a closed oscillating circuit consisting of spark gap, condenser, and variable inductance.

The spark gap is an eight section Quenched-Spark Gap arranged in an insulated frame. The condensers are of tinfoil, insulated with paper saturated in paraffin wax, and are mounted in wooden cases with connecting terminals.

The inductance consists of a flat coil of copper strip and is provided with connections for adjusting to various wavelengths. For the purpose of accurate adjustment to the aerial circuit, a

helix with a sliding contact is also fitted, seen in the top right-hand corner of Fig 159 *c*.

Within the range of 600 to 1500 metres four waves (600, 900, 1200, 1500 metres) can be used, and to change from one to the other is a matter of only a few moments.

The high-frequency energy produced in the primary circuit, is transferred to the aerial which, by means of a variometer, can be adjusted to the same waves as the excitation circuit, accurate adjustment being shown by the maximum reading of the hot-wire ammeter connected in the leads to the counterpoise. This variometer consists of a series of fixed and movable coils moving along the common axis by means of the handwheel seen above them.

Two similar receiving apparatuses are provided, Fig. 159 *d*, each having a continuous-wave range of 300 to 3000 metres. This duplication allows two operators to simultaneously receive a message and so check each other, also ensuring safe reception should one receiver be put out of action.

By means of a Double Receiving Switch, which is often provided, two telegrams may be received at the same time from the same aerial, provided that they are of different wavelengths.

Various spare apparatus is carried within this wagon, together with a wavemeter for tuning the various circuit.

The second four-wheeled limber carriage is used for transporting the mast with the aerial, counterpoise and accessories, and spare working parts.

The rear limber is fitted with carrying brackets for a 25 or 30 metre telescopic mast and space for packing the aerial material and spare parts. The fore limber contains space for packing working materials such as oil, petrol, etc., and is provided with seats for two men, seats for four more being provided on the rear limber. The weight of the complete wagon without men is 3300 lbs., including the men about 3500 lbs.

It is usually drawn by four horses and is designed with a view to ease of transport over difficult country.

One non-commissioned officer and six men are necessary for working this station ; but there is accommodation for twelve men on the limber carriages, so that sufficient men can be carried to provide relays to work the station continuously for any period, or to replace casualties.

The space necessary for the erection of the station is a circle of about 400 feet diameter. The erection consists almost entirely of the erection of the mast, aerial, and counterpoise, and

can be carried out in 20 to 25 minutes. A telescope mast is usually employed about 80 feet high, giving a range of 150 to 220 miles. If larger ranges are required, the height of the mast is correspondingly increased.

Automobile Stations.—Automobile stations are for use of the commanding section of an army, and are practically large land stations, transported bodily upon an automobile, ready for use as soon as a site has been selected and a suitable mast has been erected.

The largest station, 2.5 T.A.K., which has been evolved compares very favourably in range and power with many permanent coast stations, as may be seen from the following table giving particulars of the standard types :—

AUTOMOBILE FIELD STATIONS.

AUTOMOBILE.

Horse-Power.		Velocity.		Weight with Apparatus.	
18-24		40-50 miles per hour		About 6000 lbs.	
19-45		20-25	" " "	"	8800 "
35-45		20	" " "	"	9500 "
WIRELESS APPARATUS.					
Energy Used.	Energy Radiated.	Masts.	Range Miles.	Time for Erection Minutes.	Wave-length.
1.5 kw.	0.5 kw.	2 of 40 ft.	100-150	15-20	} 450, 600 900, 1200 600, 900 1200, 1500, 1800
2.5 "	1.5 "	1 of 80 "	150-220	15-30	
5.0 "	2.5 "	2 of 80 " or one of 115 ft.	250-375	according to type of mast	

This class of station is built into automobiles which may either be of the limousine form with doors at the sides, or of the omnibus form with the door at the back. The car transports a light collapsible mast outside, and inside six to eight men to erect and work the station, the interior being illuminated electrically from accumulators.

Energy for the wireless apparatus is derived from the engine of the car when this is not moving, the change from driving to transmission being carried out by means of a lever at the chauffeur's seat.

The motor has a normal speed of 850 r.p.m. with four speeds forward and one reversed. Magneto ignition is provided, and the ball bearings are kept automatically flooded with oil by a small pump. Owing to the hard service experienced in actual warfare, all parts are made easily replaceable, in case this is necessary.

The 500-period generator for the wireless transmitter is coupled to the automobile motor and excited by a small directly-coupled continuous-current generator. This generator is mounted beneath the floor of the motor and is accessible by means of a trap.

The transmitting apparatus is seen in Fig. 160 upon the right-hand side. The pressure and current from the alternator is controlled by the ammeter, 7, and voltmeter, 7, in the top corner and a sliding resistance, 5, upon the extreme right of the table. This current feeds through fuses, 1, resonance choke-coil, 2, and 8000 volt transformer, 3 (seen beneath the table), an excitation circuit consisting of a spark gap, 7, upon the table, excitation inductance, 6 (upon the wall), and paper condensers, 8 (beneath the table).

The aerial circuit consists of the variometer, 9, in the centre of the table (which can be operated by the handle, 10, above it), and then passes to the aerial through one leading-in insulator, 12, and through the aerial ammeter, 11, to the counterpoise through the other of the leading-in insulators, 13, which may be seen in the upper corners of the car.

Between the aerial leading-in insulator and the transmitting apparatus is seen a small helix, 14. This helix induces upon an aperiodic circuit behind it, which serves, by means of a detector and telephone plugged into it, to control the note emitted by the transmitter.

The telegraphic apparatus is arranged upon a table in the front of the car after the manner shown. Upon the left side and mounted upon the wall is the flat Universal Receiver, 15, with separate variable condenser, 16, and beneath the table is a wave-meter, 17, for testing purposes, tools and spare material, 18.

The form of aerial adopted is usually an "umbrella" of twelve wires supported by a telescopic mast which is carried in section by the side of the car.

With the larger stations a second car transports a lattice mast for replacing the telescopic masts, if the headquarters are to be fixed for any considerable period.

Semi-Portable Stations for Railway Requirements.—In



FIG. 160.—Automobile station.

[To face p. 328.



connection with the installation of wireless telegraph apparatus for railway signalling and telegraphic purposes, which, in 1914, was greatly boomed in England as a new wireless departure, owing to the installation on American railways, it is interesting to note that such installations were carried out upon the German railway between Marienfelde and Zossen as long ago as 1902.

The history of such experiments is even much older than this, since by conduction along the railway lines, experiments were carried out as long ago as 1890 by Phelps, Brown, Edison, Gilliland, and others.

Since the advantages of wireless telegraphy over other available methods of railway signalling, quite automatic and less liable to mistakes due to the personal element, are not very great, it is hardly necessary to deal with this subject to any great length, and those requiring further information are referred to the "Electro-Technische Zeitschrift" of 1906, Heft 39, where a very full account of the Braun-Siemens' experiments will be found.

The non-moving station has an aerial fixed between the normal telegraph posts, and it was found the ordinary telegraphic wires along the track greatly assisted the propagation of the electro-magnetic waves.

The necessary power for the station installed on the train was obtained from accumulators which somewhat restrict the range, or, upon electric railways, from a special motor-generator taking current from the railway system.

The wireless apparatus is similar to the normal forms of portable stations and does not call for special comment.

The most characteristic part of the installation is the aerial which is placed upon the roof of the vehicle (see Fig. 161). These are necessarily restricted in height by tunnels along the route, and the installation is not therefore capable of very long ranges. This is, however, not required, since the distance between stations is rarely very considerable.

As an earth, the carriage of the wagon is used, making contact with the rails. Communication is carried out upon the 300 metre wave either by continuous messages or automatic bell signals.

This method of communication is doubtless most likely to be useful on large transcontinental railways where the stations are long distances apart and where the normal telegraphic wires, and even the track, is likely to be destroyed, by means of landslides, storms, etc.

On long-distance transcontinental routes further advances in wireless telephony technique will doubtless cause this method to be more useful to allow business transactions on the part of passengers when on board express trains.

A somewhat analogous installation came under the author's charge in France, where an installation was fixed upon an armoured train in order to receive artillery observations from aircraft. Here, however, special masts were erected on the train,

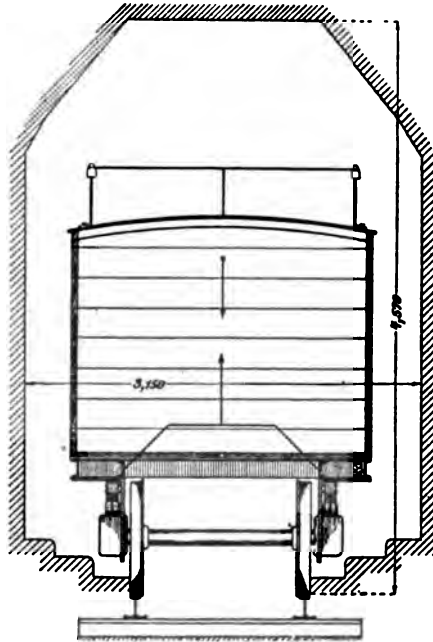


FIG. 161.—Aerial and earth arrangement with railway installations.

which did not have to pass under any railway arches but only between its hiding position and its battle position. The aerials were hinged to the roof and lowered whilst the train was in motion.

According to Meissner, reviewing the progress of wireless telegraphy during the war in the "Electro-Technische Zeitschrift," of January, 1919, the Germans have installed a 6 kw. station upon a railway train. The object of such a high-power set is not mentioned, and it would appear to be rather unnecessary, unless it was upon the state train of the ex-Kaiser to

permit him to keep in touch with the various German armies, a use which would possibly not commend itself to the various German commanders.

Very analogous to the installation of railway trains with wireless was the installation of some of the tanks during the later stages of the war. The possibilities in the tank being able to keep in touch with headquarters behind, so that its movements could be directed, are obvious.

The chief trouble in such installations was due to the noises both internal and external, and to the very limited space which could be apportioned to the wireless apparatus, which did not, however, require a very wide range.

As an earth the metal body of the tank was used, with earth mats dragging behind if necessary.

As an aerial the induction system with trailing wires was preferred, since any true aerials above the tanks, although sometimes fitted, were so easily destroyed by shell fire, etc.

Special British Army Apparatus.—On the Western Front the larger military wireless stations, with the exception of the pack sets, were practically unused throughout the war, since, both sides having "dug-in," permanent civil or military lines were used. Such larger stations were stationed very far behind the line, and conditions were no different to those obtaining in England.

As already mentioned, such spark stations nowadays employ a Siemens' Quenched Gap, as may be seen on referring to Fig. 162 *e*, showing an actual present-day British Army spark station.

All Army wireless work came under one of four heads:—

1. Trench installations.
2. Observing work in the Air Force.
3. Interception work in the trenches.
4. Direction-finding work carried out well behind the lines by special staff.

Of the trench installations two were in chief use, one a spark set, used in the early days of the war for which nothing can be said in its favour, and one a C.W. set, used towards the end of the war, which is possibly the best C.W. transmitter of its size and type.

The original trench "B.F. set" was worked from a small induction coil fed by an accumulator battery, instead of a hand-gear generator, as illustrated in Figs. 157 *a* and *b*, as should have been the case, since the accumulators, under trench conditions, were a constant source of trouble.

Otherwise, it had a small open spark gap and the excitation and aerial circuits were magnetically coupled. From bitter experience the author can only say that such an instrument should never have been permitted to have been used in situations where the lives of the infantry might depend upon it. It was not only badly designed for transport in the narrow trenches, but it was of extremely bad electrical design, and as regards its mechanical design, one firm, asked to quote for its manufacture, is reported to have stated they had no facilities for carrying out such shoddy work and would be pleased to quote if they could redesign it.

A somewhat better designed but more bulky set was known as the "Wilson set". This was of much better design, had a separate receiver, and used an induction coil, with a commutator interrupter driven by a small motor. Unfortunately these sets, much superior to the B.F. set, were limited in number in the front line where they were most required.

The later C.W. Transmitter Mark III. deserved as much commendation as the B.F. set deserved condemnation. It was produced by the Experimental Signals Establishment at Woolwich.

This instrument used the hard French valve, the filament of which was heated by a 6-volt accumulator battery. The high-tension supply was from a battery of "ever-ready" cells, although later it was attempted to replace these by a specially designed induction-coil type interrupter.

The general design of this instrument, which embodied first-class design and manufacture, was in a mahogany case, sufficiently small to be transported upon the back in a knapsack, a method of transport not possible with the earlier B.F. set.

The actual arrangement of the instrument was as shown in Fig. 162 *a*, whilst the systematic arrangement is seen in Fig. 162 *b*.

The aerial was led to the terminal, 1, situated on the left top corner and then to the aerial ammeter at 2, the ammeter terminals 2 and 6 being capable of being short-circuited by the switch, 3 and 4, which automatically inserted a 10 ohm resistance, 5, to compensate the aerial for the withdrawal of the ammeter resistance.

From the ammeter, connection was made to a small bus-bar, 7 (for connection to the plate circuit), then to the aerial condenser, 7 and 8, and aerial inductance, 9 and 10, parallel to each other and both variable in order to tune the aerial. From the zero battery terminal, 11, in connection with both aerial inductance and capacity, the aerial circuit was completed to the earth at 14,

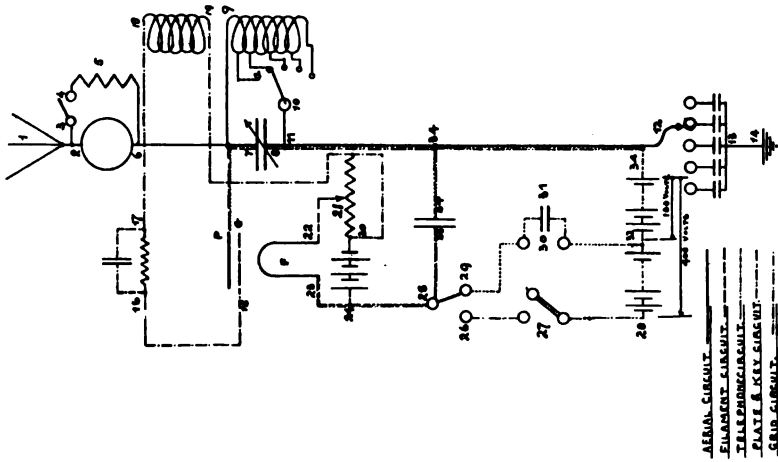


FIG. 162 b.

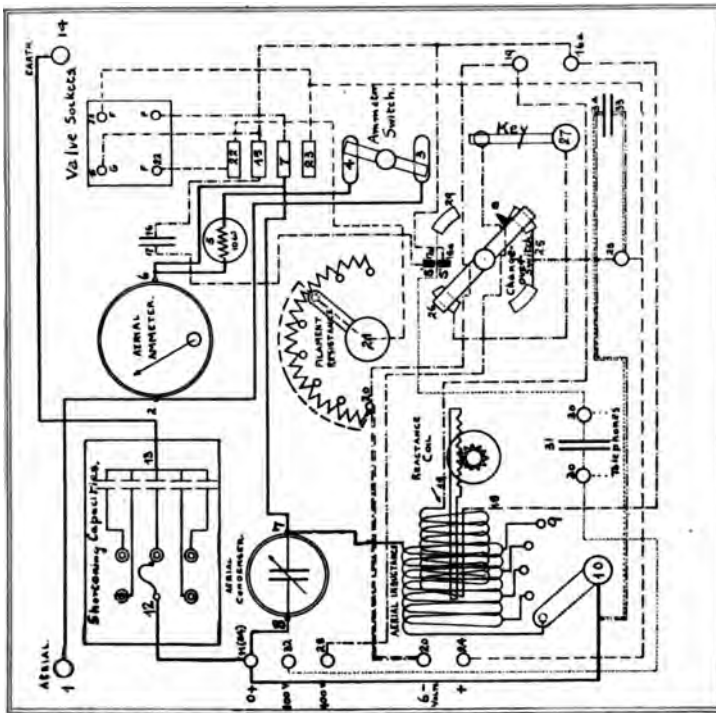


FIG. 162 a.

via a very neat little series of shortening capacities, 13, each of different capacity, any of which could be put into the aerial by a flexible plug at 12, the plug being inserted in either of five sockets.

The grid circuit, commencing from the grid plug socket of the valve (accessible from the right-hand side), was taken to a small bus-bar at 15 and, for reception, then to a grid condenser and resistance, 16 and 17, thence from the terminal, 16 *a*, to the reactance coil, 18 and 19, giving a variable reactance to the aerial inductance by means of a spur wheel gear worked by a handle, altering relatively the longitudinal axes of the two coils. Hence the grid circuit was completed to one end, 20, of the filament resistance and to the negative end of the filament battery. During transmission the grid condenser and its resistance was short-circuited across 16 *a* and 17 *a* by spring clips separated, during reception, by entrance of a projection attached to the change-over switch.

The filament battery of 6 volts was, from the positive terminal of the battery, connected to terminal 24, thence to a bus-bar, 23, and valve plug sockets, 23 and 22, bus-bar, 22, variable resistance switch, 21, and so back to the negative pole of the battery, 20, via a lead common to both grid and filament circuits.

The plate circuit commenced from the plate valve socket making connection with the aerial circuit at 7 and included as its oscillatory circuit, the aerial inductance and capacity across 7 and 11, then to the high-tension battery terminal, 34. In order to render this circuit oscillatory the battery was short-circuited across terminal 3 and 4 and the change-over switch at 25, by a condenser, 33 and 34.

The completion of the plate circuit then varied by means of the "send-receive" or change-over switch according as to whether transmission or reception was being carried out. This switch from a common end, 25, making connection from the filament at 23 via the positive battery terminal, 24, during transmission inserted at 26, the sending key, 27, connected at terminal, 28, with the whole of the four hundred volts of the high-tension battery, the grid condenser being short-circuited. During reception this grid condenser was put into the grid circuit, whilst the plate circuit, instead of through the key, was completed across the switch from 25 to 29 and so to the telephone condensers at 30, and to one hundred volts of the high-tension battery, tapped off by terminal, 32. The telephones were in parallel to a blocking condenser, 31, and in the actual instrument, but not shown in the diagram, a built-in step-down

telephone transformer was inserted between the telephones in the sockets, 30, and the actual plate circuit, for reasons already explained in Chapter VII.

The parts visible from the top of the instrument were the aerial and earth terminals, the aerial ammeter and its short-circuiting switch, the handles to vary the aerial inductance and capacity, and the aerial shortening capacity plug.

The filament resistance was adjusted by a handle in the centre, below which was the reactance handle, to the right the Morse key, and between them the "send-receive" switch handle.

The telephone terminals were nearest the operator and the valve itself was accessible, for replacement, etc., by a small trap door on the right vertical side.

The adjustment of this receiver was as follows:—

To receive the "send-receive" switch was put over to "receive" and the filament current adjusted to about mid position. A small wavemeter was then, by its buzzer, caused to induce upon the aerial. With the reactance tightly coupled the aerial condenser and inductance were adjusted. If the buzzer gave a musical note, i.e. the valve was not oscillating, the receiver was in the condition to act as a detector and so receive spark signals, whereas if the musical tone of the buzzer was destroyed and a warbling sound heard, the receiver was oscillating and ready for continuous-wave reception, in which case sharp clicks were heard on moving the aerial condenser to its extreme positions, and incoming spark signals would be heard without their musical note.

To transmit on the same wavelength it was only necessary to change the "send-receive" switch, but the aerial current was adjusted to a maximum by means of the reactance and the bank of five condensers, after which the aerial condenser and inductance were altered to give an aerial tuning, according to the best reception of a wavemeter buzzer signals of known wavelength.

The apparatus employed a single hard French valve.

The foregoing installation is designed for use at Battalion and Brigade Headquarters. For use with Divisional and Corps Headquarters, a similar 60 watt C.W. installation has been designed.

This is manufactured in separate portable units but is intended for transport upon a light automobile. With 15-foot masts and an L or T aerial 150 feet long, the range is 10 miles, whilst with 48-foot masts a range of 100 miles can be obtained,

over a wave range of 200 to 3000 metres, using for reception a 3-valve amplifier.

The Army Signals Establishment has also developed a larger 120 watt C.W. set, mounted upon a light motor lorry. As a receiver the Siemens' Universal Receiver has been adapted for valve reception.

This installation is for use at General Headquarters and Army Headquarters. Its range with a similar station is 200 miles with a factor of safety of 2, but it is not stated whether this is the day or night range.

The aerial used is a double wire T or L aerial, 300 feet in length, and supported by two 48-foot masts. The wave range is 450 to 2500 metres, giving an aerial current of 1.5 to 2.0 amperes. By means of lengthening coils, but at the expense of range, wavelengths up to 8000 metres can be used.

The means of transport for the instrument case and aerial material is a light Crossley tender, which also transports the high-tension and low-tension batteries situated beneath and behind the driver's seat.

The instrument case is shown in Fig. 162 *a*. To the left is seen the continuous-wave transmitter, behind which the shaft of a small rotary converter (which is the source of alternating energy) can just be seen. Above and upon the wall is the aerial ammeter.

To the right of the transmitter is a valve rectifier for converting the alternating energy from the converter to unidirectional pulses.

In the centre is the switchboard having tumbler switches and fuses for the battery supply, and above two voltmeters which can, by means of the switches in the upper corners, be put into various circuits.

One, reading 0 to 10 volts, can be put into the filament circuits of the transmitter, rectifier, amplifier, or receiver valve (for C.W. beat reception (heterodyne valve)), according to the position of the switch. The other, reading 0 to 60 volts, can be put into the 22-volt rotary converter supply circuit, or the high-tension circuits of the various valves already mentioned.

Below the switchboard to the right is a C mark IV. 3-valve amplifier, which does not offer any special amplifier features except that of great compactness. In front of this is the transmitting key.

To the extreme left is the adapted Siemens' receiver, with which an "heterodyne" valve has been mounted upon the base



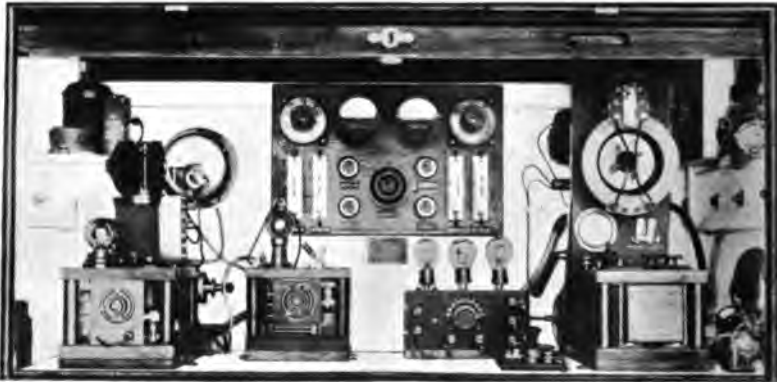


FIG. 162 *c.*—A British army 120 watt C.W. field set, showing adaptation of the Siemens' receiver.

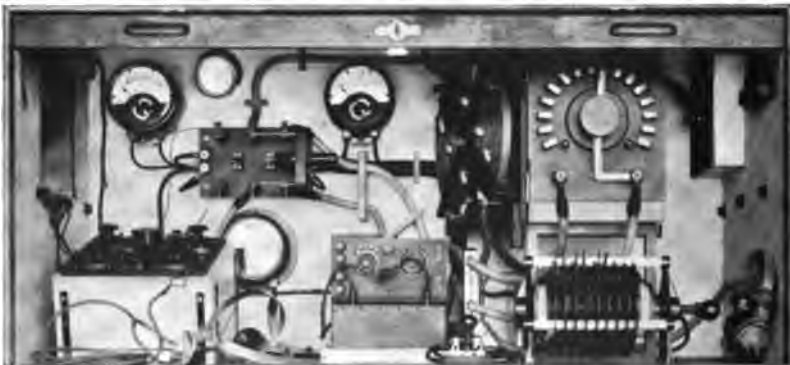


FIG. 162 *e.*—British army light motor set, showing adoption of Siemens' Quenched-Spark Gap.

[To face p. 337.]

for valve reception. As usual the change-over switch of this receiver (as described on pages 104-107), makes all sending circuits when at "transmitting," i.e. connects aerial and earth to the transmitter, supplies current to start the rotary converter, switches on the filament currents to the sending valves, and short-

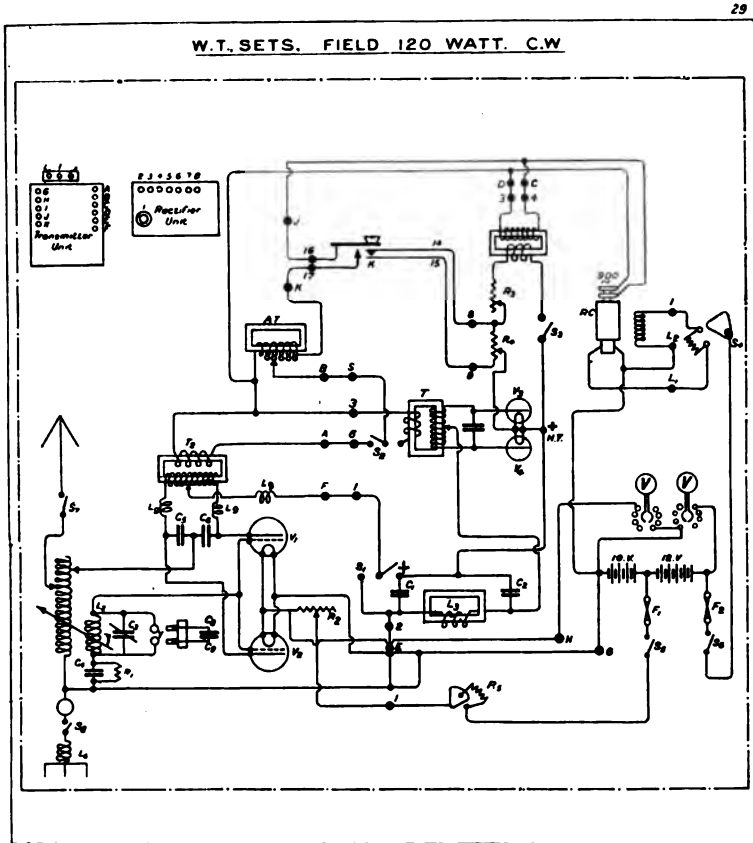


FIG. 162 d.—Connections of British army 120 watt C.W. transmitter.

circuits the resistance R_5 (Fig. 162 d). When at "receive" all these circuits are interrupted, the aerial and earth are connected directly to the receiver, and the filament circuits of the receiver heterodyne valve and amplifier are made.

The actual connections of the transmitter are shown in Fig. 162 d.

Starting from the 10 and 12-volt accumulator batteries, the

former of these through the fuse F_1 , and tumbler switch S_5 , protective resistance R_5 and variable resistance R_2 , supplies the filaments of the transmitting valves V_1 and V_2 , returning to the battery via the point H. Across this battery the left-hand voltmeter can be placed for control when the switch is on the appropriate studs.

This battery, in conjunction with the 12-volt battery, also supplies the field and armature circuits of the converter, via fuse F_2 , tumbler switch S_6 , protective switch S_4 , which cuts out a resistance in the field coils between L_1 and L_2 of the rotary converter. The voltage across the entire battery is indicated by the right-hand voltmeter V.

The rotary converter generates 120 watts of 900 cycle single-phase current at a voltage of 35, with a speed of 4500 revolutions per minute.

This energy can be utilised to supply the transmitting valves either directly or via a double 2-electrode valve rectifier.

For direct excitation the circuit passes via the key K, across the points 16 and 17 to the auto-transformer AT. This transformer has five tappings by which transformation ratios of .28, .46, .65, .84, or 1.0 can be obtained.

Thence via the switch S_2 mounted upon the receiver "change-over" switch the primary of the transformer T_2 is excited. From the secondary of this transformer, the current at a voltage of about 1500 is applied across the filaments and plates of the generating valves V_1 and V_2 . To prevent back surges of high-frequency energy into the transformers and converter, the air-chokes L_3 are inserted, and in order to give a lead to the current the condensers C_5 and C_6 are inserted.

The plate circuit is direct coupled to the aerial across the aerial inductance (seen in the photograph above the transmitter), and reacts with the grid circuit formed by inductance L_3 , and variable condenser C_3 (.003 mfd.), this circuit having a high resistance leak R_1 and grid condenser C_4 (.002 mfd.). To tune this circuit to the higher wavelengths, the capacity can be increased by insertion of condenser C_8 and C_9 (.0025 mfd.) in parallel to C_3 , by means of the sockets Y.

With this method of utilising the alternating current, each half cycle is utilised by either of the two valves. The generated aerial oscillations are nearly pure continuous waves at long ranges, but for short distances, up to 20 miles, the ripples from the rotary converter can be heard.

Such ripples can be eliminated by use of the rectifier. In

this case the alternating current from the rotary converter passes, the switch S_2 being open, via the points D and C (3 and 4), to the primary windings of the step-down transformer (ratio 5·5).

The secondary of this transformer is then (the switch S_3 being closed) applied across the electrodes of the two 2-electrode valves V_3 and V_4 , via the sliding regulating resistance R_3 , and the resistance R_4 . The latter is inserted so that, when the transmitting key is depressed, the resistance R_4 is cut out, the energy to the valves is so increased, and a steady output is obtained during the periods of load and non-load.

After the valves V_3 and V_4 have rectified the alternating current (since current can only pass from anodes to heated cathode filaments, and not vice versa), the unidirectional pulses so produced feed across the transformer T, which acts as a choke coil, and then across the capacities C_1 (·1 mfd.), and C_2 (·3 mfd.) at a voltage of 2000 volts. These condensers of large capacity and the choke coil L_3 serve to smooth out ripples from the rotary converter, and deliver energy at a steady voltage of 2000 across the filaments of the transmitting valves, V_1 and V_2 , and to their plates, via the positive side of the switch S_1 and the transformer T_2 , as in the case of non-rectified current.

The aerial circuit is broken during reception at the points S_7 and S_8 by means of the change-over switch of the receiver, which simultaneously operates the switches S_1 to S_6 and the resistance R_4 .

To obtain the necessary beat formation during reception, a valve circuit generating undamped oscillations of slightly different frequency is caused to excite the aerial across the inductance L_6 , and so produce beats.

The valve (with a plate voltage of about 18), generating oscillations for this heterodyning circuit is mounted within the base of the Siemens' Receiver, the filament current being indicated by an ammeter mounted upon the receiver back. The capacity of this heterodyne circuit is also mounted within the receiver base, and the inductance is in a flat case which can be seen in the illustration upon the front of the receiver base. This inductance can be one of four coils which permit in all a receiver wave range of 450 to 8000 metres to be obtained.

This heterodyne circuit, the frequency of its regular discharge via the grid leak being within audible limits, can be used as a wavemeter to tune the aerial circuit, which by three inductance coils, give ranges of 450 to 1600 metres, 1200 to 2200 metres, 2000 to 8000 metres.

The audible beats produced by the receiver may if desired be intensified by the 3-valve instrument already mentioned which has a plate voltage of 60.

Similar but larger installations to that just described have been designed, the largest being a 500 watt set, with a range of 800 miles by day. It is to be regretted that these installations have not adopted the more rational classification of aerial output, rather than that of converter output.

Very many types of amplifiers have been evolved at Woolwich, the latest of which has been illustrated in Chapter VII. It would entail too much space to describe all these various types of apparatus, which have been rendered possible, since expense has not been a very great consideration. Details of such apparatus is available to many people, who know where to refer to Experimental Signals Pamphlets, etc. It is to be regretted that now the war is over such pamphlets cannot be purchased. The accessibility of such information, obtained at the nation's expense, would further the general progress of wireless technology. Its withholdance can hardly be said to be on grounds of secrecy, since the army apparatus is not only known, but copied and even patented by commercial companies, so that its secrecy is already destroyed irrespective of such companies' foreign connections.

Interception Sets.—These require little further description except to mention they are two or three-valve amplifiers, using the French valve, in the normal way, i.e. in cascade.

The earth lines for interception either took the forms of multiple loops of army D. 3 cable wound round the front and support line trenches, or earth wires run out in front of the trenches and pinned into the ground by a bayonet, or similar implement.

The original French three-valve amplifier was the best valve amplifier which, up to its appearance, had been produced and was the first practical hard valve amplifier. Electrically it was very well made, but it was of very great size, and only those who have spent days and nights transporting it around front line trench bays know how awkward it was mechanically, so awkward that at night, rather than undergo the trouble and fatigue of such transport, it was usually preferred to carry it over the top even to within a 100 or so yards of the German trenches.

This original French amplifier was for "secrecy" christened by the Intelligence Corps as "IT," with the result that every telegraph operator having to transmit a message concerning, it enquired what "IT" was. Whereas the word "amplifier" would

have passed unnoticed, this super-intelligent term "IT" caused it to be the most well-known instrument in the trenches, so that the object of its name was entirely defeated.

The latter forms of both British and French amplifiers (the latter army displaying special prominence in their production) were all much smaller and more convenient than the original one, which, however, rendered a very good account of itself.

It appears to the author to be unnecessary to give further details on earth induction methods, since now the war is over they are unlikely to be of much importance. Just as in aeronautics, war conditions demanded a rapidly climbing aeroplane, of little use in commercial flying, so the war demanded earth-induction wireless telegraphy, offering no advantages commercially over normal aerial wireless telegraphy.

This method was developed by the combined work of Morse (1846), Bell and also Dolbear (1882), notably by Sir William Preece in 1898, and later by Kiebnitz in 1911, whose paper (and that of Burstyn) in the "Jahrbuch der drahtlose Telegraphie," Vol. VI, and the "Electrician" of 8th March, 1912, entitled "Recent Experiments on Directive Wireless Telegraphy with Earth Antennæ," should be read by those interested.

One use of the induction system which may later develop, however, is to maintain communication in mines. It was first used by Heavyside at Broomhill Colliery in 1887 and later by Reineke (British Patent 15,256, 1912), who proposed a partly conduction method along existing pipes and rails in such mines and partly inductive. This method, using a low voltage, was stated to be safer from danger of sparking than using ordinary lines, and might also be available after mine disasters, especially should any miners be entombed and able to use Morse. Such installations were actually also carried out for telegraphy and telephony at the Carolinenglück Pit in 1912 (Science Abstracts 16B. No. 103, 1913).

A similar use was proposed in France in 1916 to maintain communication between the battalion which in this year attempted to capture the Double Crassier near Loos, and the front line trench, after the ordinary wires had been wholly or partly destroyed by the heavy enemy barrage. The night before the night of the attack the author laid his base line, but at the last moment the experiment was stopped by headquarters. Later, by means of powerful buzzers this method of maintaining communication with valve receivers was, the author believes, very much used in actual operations to maintain actual communication over shell-swept areas, where lines could not be maintained.

CHAPTER XII.

WIRELESS TELEGRAPHY IN AERONAUTICS.

THE chief use of aircraft up to the present time has been for military purposes, such as bombing and the control of artillery fire.

This use mainly grew up during the late war. Previously, aeronautics was very largely a form of expensive sport, if we except the establishment of a system of Zeppelins in Germany in order to carry passengers and cargo between the principal German towns. More recently aerial services between England and France and Holland have been established, and other similar services are proposed.

For any of the above purposes aircraft are at a great disadvantage if they cannot receive and send information during the course of their flight. This is particularly the case in military observational work, since otherwise, not only is the effective period of the machine curtailed by the time necessary for flight to and from its base, but also the information it may obtain is, on its return, of less value owing to the consequent lapse of time.

For signalling purposes to and from aircraft the only available method is by means of wireless telegraphy or telephony, if we except the semaphore and flare methods, used in the very early days of aircraft, which was both cumbersome and slow, not available at high speeds, or during fog and other periods of low visibility.

The installation of wireless upon aircraft not only facilitates the navigation of the vessel by enabling it to receive meteorological information regarding the approach of fog, storms, high winds, etc., but increase in the sensitiveness of wireless receiving apparatus has quite recently enabled aircraft to actually determine its position by the use of wireless direction-finders. One of our R.A.F. machines has successfully travelled between England and Paris solely by means of its wireless direction-finder.

The first attempt to employ wireless telegraphy upon aircraft, appears to be due to Slaby in 1898, working in conjunction

with the Prussian Airship Corps. The attempt was carried out with balloons. Owing to the undeveloped state of wireless technology at this period, it was only found possible to equip the balloons with receiving apparatus, since the heavy old-fashioned wireless transmitters were of too great weight for the carrying capacities of the aircraft. Later still, in 1910, wireless apparatus was employed upon the ill-fated airship of the Wellman Airship Expedition.

For some years previous to the war, a very extensive system of wireless radiophares had been established all round the frontiers and sea coast of Germany, to enable Zeppelins to determine their geographical positions. These stations were of the Telefunken Compass type. The aerials were cheaply obtained by the use of existing smoke stacks, etc., and the stations were entirely automatic in operation. With this system aircraft could determine their position, if provided with a simple aerial, a receiver, and a stopwatch. Most of the vessels also carried transmitting apparatus.

For navigation of Zeppelins outside Germany during the late war, the vessels themselves transmitted signals and their position was then worked out by stations in Germany, either by use of the Artom apparatus, or a receiving form of radiophare. The result was then transmitted back to them. Such a method was, however, twofold in its uses, since, by the frequency of signals during such operations, the probability of an air-raid could be determined, and by use of direction-finders in Britain the actual course of the hostile air vessels could be followed.

This method of obtaining intelligence was greatly developed in Britain, so much so that in the raid in 1917, when five Zeppelins lost their position and drifted over to France and were there brought down, it was commonly said that the cause (given in the Press as an "electrical storm") was the employment by us of a number of Quenched-Spark Army stations, which were used either to jam the German transmitted wireless direction-giving signals, or to even transmit false direction-giving signals.

As far as the equipment of air vessels in Great Britain before the war was concerned, whilst a few vessels had been equipped, the whole problem was in a very backward state, largely owing to the general lack of interest in aeronautical matters in England, as compared to Germany, where aeronautical engineering, especially with reference to airships, had been very seriously taken up for many years.

After the outbreak of war, the rapid and large development

of aeronautics in Britain by the Royal Air Force (at this period the Royal Flying Corps), caused attention to be drawn to the use of wireless in aeronautics. Whilst the aviator at first regarded this as a somewhat unnecessary accessory, the work of Prince, Robinson, and others of the R.A.F. soon proved, not only its value, but its absolute necessity.

The growth of valve work for telephony caused attention to be devoted to telephony, and Prince claims that as far as he is aware, a wireless telephony valve set installed for the R.A.F. in 1915 was the first telephony set ever installed in aircraft, a statement which, until further information regarding the progress made in Germany is available, must be accepted with reserve. Valve transmission being originally due to Meissner in Germany, it is hardly creditable that, with the German interest in aircraft, it was not very early applied to purposes of aeronautics.

Fundamental Requirements of Wireless Apparatus for Aircraft.—The fundamental consideration is that of weight of the generating plant and telegraphic apparatus. This must be of very light construction, all metal being, where possible, aluminium or one of its alloys.

The question is most important in aeroplanes, and until their growth in size and power during the past few years, the use of wireless for aeroplanes was restricted as compared to its use in airships. The latter could not only carry a heavier and higher range installation, but could also devote greater space to the installation, restrictions of size as well as restrictions of weight, occurring on all aircraft.

Another consideration with airships, employing gas-filled balloons, is the very important question of prevention of sparking. The cause of the loss of at least one of our airships patrolling the North Sea, was attributed to either unauthorised smoking on board, or sparking due to the wireless apparatus.

All aircraft can naturally not obtain a true earth, and a counterpoise has to be provided in place of an earth. This is obtained partly by the use of the fuselage and partly by the installation of a special wire arrangement around the wings of an aeroplane or the balloon of an airship. All metallic portions of the machine are also electrically connected by suitable wires, a process known technically as "metallising". For convenience many writers refer to this counterpoise as the earth.

In airships, and much more so in aeroplanes, the noise of the engines is very great. So it is often impossible to hear





FIG. 163.—Silence helmet for aeroplane wireless telegraphy.
[To face p. 345.]

incoming telegraphic signals, and even less possible to hear telephony signals. Reception is therefore only rendered possible by building the telephone ear-piece into a very heavily padded helmet as shown in Fig. 163. Such helmets usually have only one ear-piece, the other being open so that a pilot can listen to his engine, or, otherwise, if he desires. This helmet not only prevents interruption due to external noise, but may also serve to protect the aeronaut from the effects of cold at high altitudes. It is a matter of physiological accommodation which ear the airman uses with a helmet having one ear-piece open.

A further source of trouble may be due to oscillations, generated by sparking at the brushes of the magnetos of the engine. This must be prevented by correctly designed metallic shields around the magnetos. The whole question of external noises is most important in telephony, since it is more difficult to interpret modulations in the pitch of the voice, than to interpret Morse signals. Experience shows that a very high-pitched squeaky voice is better heard than the normal lower-pitched voice.

Of the most important questions involved in aircraft wireless design, we may finally mention that of simplicity of design. It is readily realised that the training of an aeronaut involves very many considerations, so that only a short period can usually be devoted to wireless training. The chief requirement is ability to read Morse, rather than any great technical knowledge. Hence as a general rule the airman has little knowledge of wireless technology. Even if this is not the case, when in actual flight, his attention must be devoted to many other matters, so that the whole design of the wireless apparatus must entail great simplicity. Since financial considerations are not so important, such simplicity can be obtained, if necessary, at the expense of the technical efficiency of the wireless apparatus.

It is nowadays customary to make aircraft apparatus as far as possible in separate units, such as one unit for the transmitter, one for the receiver, one for the telephone attachment if wireless telephony is desired. This permits any unit to be readily cut out or exchanged if desired, whilst, once the apparatus is installed, no additional adjustments are required. Fig. 164 shows the general arrangement of the most recent R.A.F. telephony set for aeroplanes.

Sources of Energy.—In the early days of the adaptation of wireless apparatus to aircraft, it was merely regarded as a possible useful accessory. For such an accessory, the weight permissible

and space possible to devote, was very small, so that only a small range station could be used.

Such small stations derived their energy from an accumulator

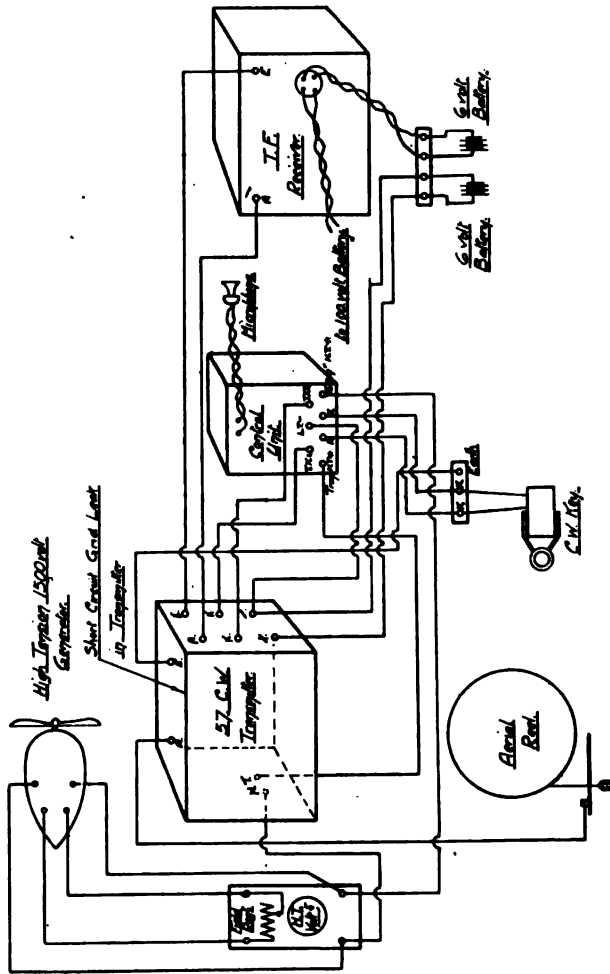


FIG. 164.—General lay-out of R.A.F. aeroplane installation for telegraphy and telephony (C.W.)

battery which, itself being heavy, again curtailed the power of the transmitter. For such a source of power the much lighter Edison nickel-alkali cell would appear to be preferable.

The growth in size and power of machines, with an excess of mechanical energy, later permitted accumulators to be dis-

pensed with, in favour of an alternator as the source of energy for the wireless transmitter. This alternator was built into the aeroplane as an accessory, after its manufacture, and was worked

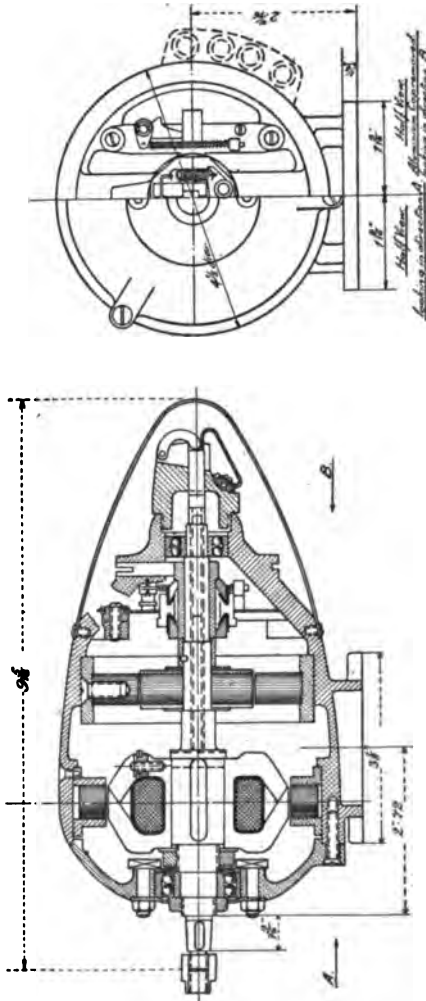


FIG. 165 a.—Aircraft self-exciting generator.

from the aeroplane engine by means of a gearing, being thrown in or out of action as desired by means of a clutch. Such alternators carried on a common shaft a small direct-current exciter, to provide energy for the alternator's field windings.

Further development of aeroplane technology resulted in the necessity of electrical energy for other purposes, such as lighting, electrical-heaters for the cockpit, etc. It so became the custom to install a complete electrical equipment during the building of the machine, direct-current being obtained by a geared generator supplying energy for the above purposes, and also for the motor-generator of the wireless installation, which was now built in during construction of the aeroplane, instead of being a mere accessory, as before.

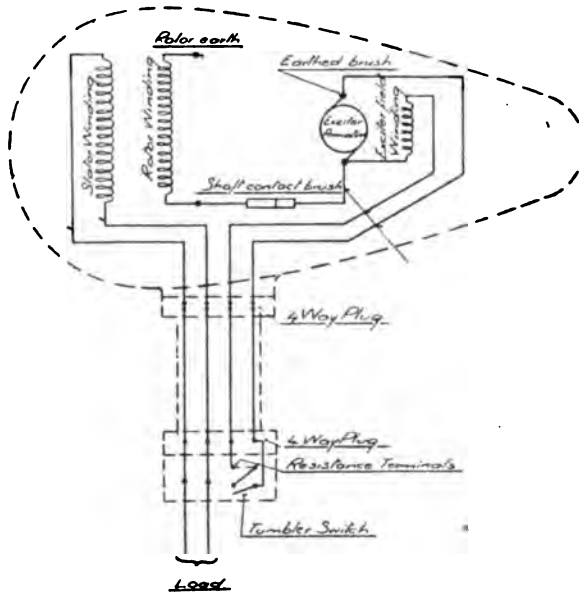


FIG. 165 b.—Connections of aircraft generator.

The introduction of valve receivers and transmitters requiring high-tension direct-current resulted in a reversal to a separate battery as the source of energy. Since, nowadays, the tendency is towards supplying such high-tension direct-currents by means of a specially designed generator (as used in the original Lieben valve apparatus), the tendency is again towards the installation of generators.

A method of obtaining energy for the transmitter at any time during flight, and also whilst the engine is shut off, is by means of an alternator driven by a small air-screw. This type of generator was originally used by the German Air Force and after-

wards also adopted by our own Air Force, who closely followed the design of the A.E.G. machine. Such a modified example is shown diagrammatically in Fig. 165 *b*. This generator has on the right a direct-current exciter supplying current to the rotating field windings wound upon the rotor.

The exciter is earthed by its common pole to the machine and the alternator field coil is similarly earthed, a method which reduces the number of brushes required. The other connection of each field winding is made by use of a hollow shaft in which the leads pass.

The air-screw was rigidly fixed to the rotor, and by the vessel's motion through the air was caused to rotate and so air-drive the generator. For mechanical protection and to remove the effects of brush sparking, the alternator was enclosed in an aluminium case.

Such a machine allowed the wireless transmitter to be used whenever the aeroplane was in the air, irrespective as to whether the engine was stopped, as during a dive. On the other hand, an objection is that the frequency of the generator and hence of the emitted wireless note, varies with the vessel's speed, since the revolutions of the air-screw and the rotor similarly vary.

In later machines this was overcome by means of a control which allowed the plane of the air-screw to be varied to the normal plane, so that its velocity and hence frequency and voltage of the generator would similarly vary.

The output of energy is controlled by a resistance in the exciter field coil circuit.

In Fig. 166, showing the lay-out of wireless apparatus on a "Bristol Fighter," the air-screw driven alternator may be seen, also the rubber cushion arrangements to protect the apparatus from shock during landing, the aerial arrangement and the provision of two telephones in parallel to allow both pilot and observer to simultaneously receive signals.

Aerials and Counterpoise.—In early days the aerial was always a hanging wire, the counterpoise being provided by the large natural capacity of the gondola of a balloon, or engine and fuselage of an aeroplane (Fig. 167 B).

When this natural capacity was not sufficiently great, a conducting net passing completely around the gas-bag was provided, as in Fig. 167 A, and has the advantage that it not only gives a large capacity counterpoise, allowing the use of a large aerial resulting in a long range with comparatively small plant, but also effectually protects the gas-balloon from the danger of sparks caused by natural electrical discharges.

Beggerow patented (D.R.P. No. 225,204) a form of aerial shown in Fig. 167 C, where the counterpoise was obtained by two

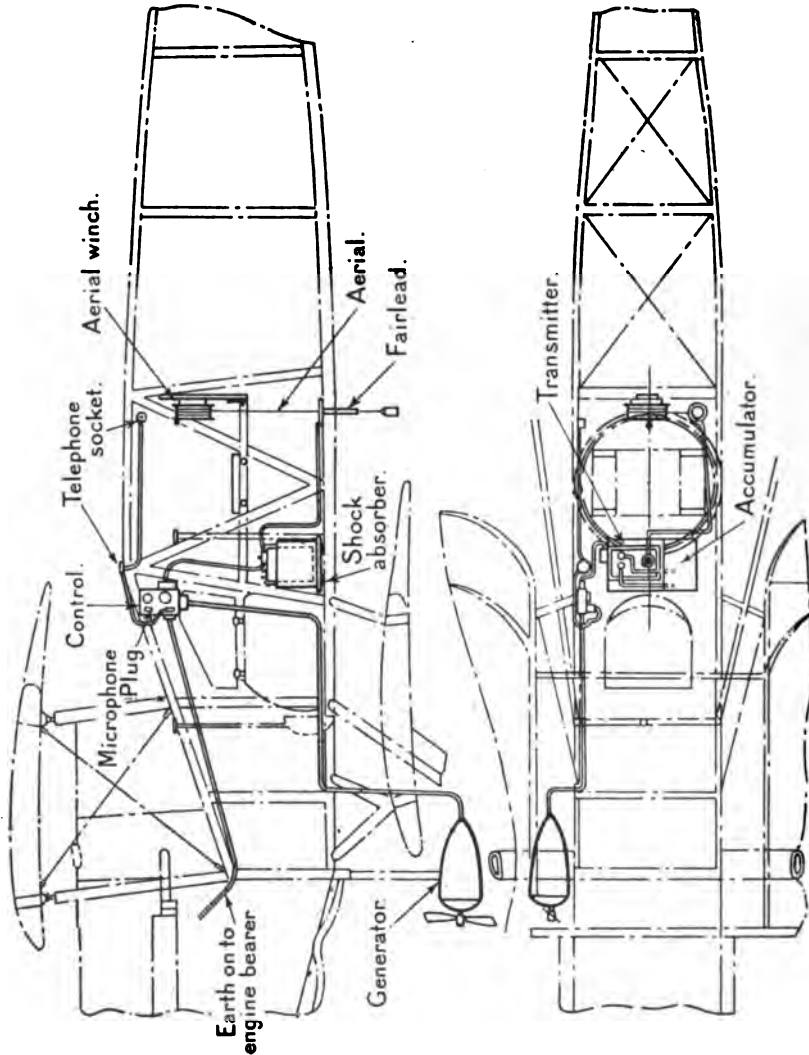


FIG. 166.—Arrangement of wireless apparatus in a "Bristol Fighter".

hanging wires, one much longer than the other, both being in metallic connection so far as length permitted. The connected portion formed the counterpoise and the free end of the one wire formed the aerial. This method not only gave a very long and

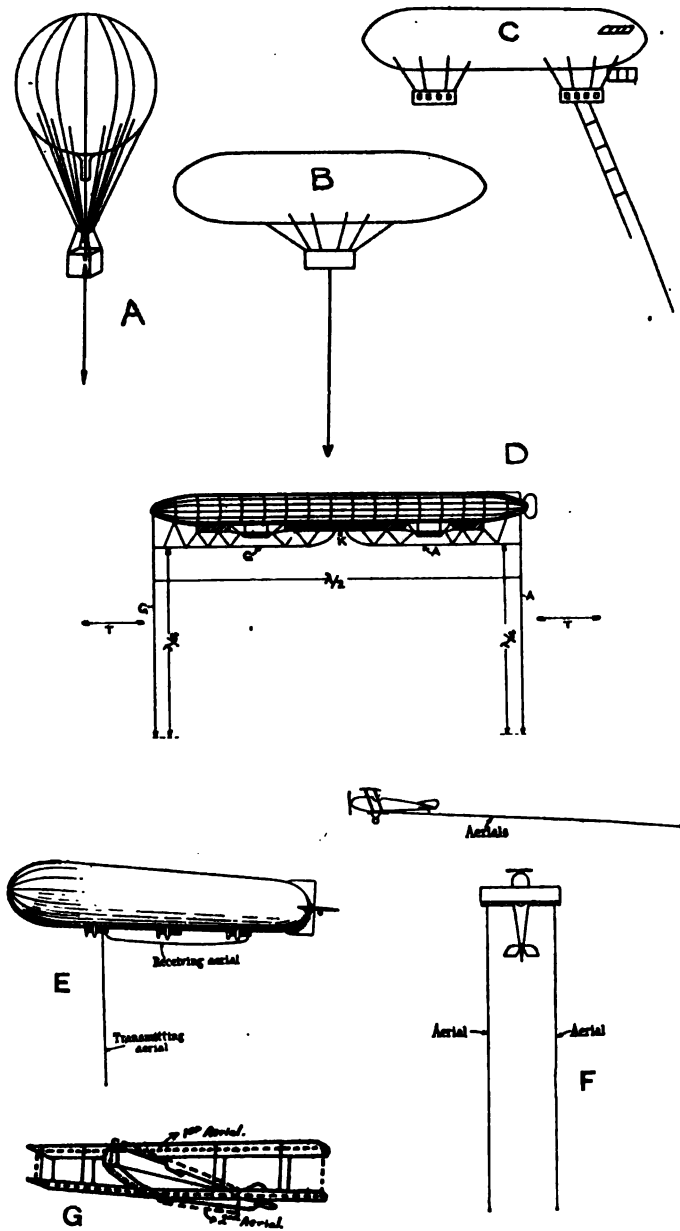


FIG. 167.—Aerial arrangements for aircraft.

efficient aerial, but also ensured that all high-tension wires were kept away from the neighbourhood of the gas-bag, so preventing danger from accidental sparking.

The type of aerial usually adopted on Zeppelins, due to Braun and von Sigsfeld, is shown in Fig. 167 D. It is stated to be highly directive in the vertical plane through the length of the gas-bag. The counterpoise is formed by the two vertical wires and the aerial by the horizontal wires, in the case when the former wires have each a length of $\frac{1}{4} \lambda$ and the latter a total length of $\frac{1}{2} \lambda$. Various wave-lengths are obtained by the insertion of self-inductance coils in the horizontal wires, and by lowering or raising the vertical wires to the requisite extent.

In order to facilitate duplex working Eckersley has proposed the arrangement of two aerials shown in Fig. 167 E, one horizontal for reception and one vertical for transmission.

A similar double aerial for duplex work, used by the U.S.A. machines, is shown in Fig. 167 F. This figure also illustrates how, during flight, the aerial trails out behind, often in the horizontal plane, altering its capacity as regards the aeroplane, so that the wavelength may vary with the velocity of flight.

The introduction of valve-receiving apparatus and its greater sensitiveness allowed the aerials to be made much smaller and more rigid, and frame-aerials could be used, permanently built around the vessel's wings as in Fig. 167 G. This also shows a second frame-aerial built around the fuselage in order to obtain a directive Artom goniometer arrangement. Frame-aerials are very largely used, but have not by any means entirely displaced the hanging type.

As a hanging aerial, if permanent, would when flying low be an impediment to the navigation of the vessel, tending to become entangled in trees, etc., it must be capable of being quickly lowered or wound up. Further, to guard against the possibilities of its becoming entangled, it must be made capable of only being able to withstand a moderate tension, so that if necessary it may become automatically detached.

The aerial wire is usually phosphor-bronze wire and is wound upon a winch. At its lower end it carries a plumb-bob to keep it taut when unwound, and also to cause it to unwind quickly when required. In the case of airship stations, this winch is above the telegraphic apparatus, and is fitted with mechanism to indicate the length unwound. It is also coloured in different lengths corresponding to the lengths suitable for the fixed wave-lengths for which the transmitting apparatus is designed. In the

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FIG. 168.—Aerial winch.

[To face p. 353.]

case of aeroplanes the winch is near the telegraphist. Such a winch is shown in Fig. 168 where the leaden plumb-bob may be seen, also a brake to stop the winch when the desired length is unwound.

The aerial is conducted by means of an insulated copper tube, away from the neighbourhood of the air-screw, and other revolving parts of the vessel, to ensure that it does not become entangled with these, and so cause fatal results. It is important that the lower end of this lead-in tube is correctly bevelled, in order that the aerial wire is not rapidly cut through by friction against the sharp edge. Often the lower end has a pair of rollers to prevent such fracture.

The aerial wire is often jointed at distances of 5 metres, so that if entangled with trees, etc., on the ground it may break off when the tension amounts to from 5 to 10 kilograms. A special device may be fitted, which automatically cuts the wire when the tension exceeds the normal tension. The aerial is in electrical contact with the winch which is itself insulated, this arrangement giving easier insulation.

With airships the counterpoise can usually be obtained by use of the gondola and extra wires around the balloon if necessary. With aeroplanes the aerial is "earthed" on the engine and metallic parts of the fuselage. If necessary, a special counterpoise is obtained by use of the metallic stays, these being "metallised," i.e. put into electrical connection with each other, if desirable.

TYPICAL SPARK-TRANSMITTERS.

Undoubtedly the best types of spark-transmitter for aircraft are those which employ the Quenched Gap.

Since the efficiency of an open spark-gap is only 25 per cent. as compared to 50 to 75 per cent. for the Quenched Gap, it is evident that, for equal range, a transmitter utilizing this form of gap may be not only very much smaller, but will have an advantage of still greater importance, namely, much less weight.

Also the use of a 500 cycle alternator, giving a highly musical note, will allow any sending station to be much more easily received upon a noisy air vessel, as such a musical note will be distinguishable from non-musical noises, or those of different musical pitch, due to local disturbances on the receiving vessel.

Whilst such an advantage of audibility can equally be obtained by means of a disc-discharger, such dischargers owing to

only partial or non-quenching, will not have such a great efficiency, and little reduction of weight as compared to an open spark set will be obtained. As far as the author is aware, any form of disc-discharger calling for additional adjustments of speed, etc., has not been used in aeronautical work.

Three types of spark stations will be described here, namely, a small type, only employing accumulators, an alternator-driven aeroplane station, and a large airship station.

Aeroplane Stations.—The smaller station is for the smaller types of aeroplanes or for balloons which observe for artillery purposes. For this purpose a range of about 25 kilometres is ample.

This station is illustrated in Fig. 169. The wooden case contains the complete transmitting apparatus with the exception of the battery of cells supplying the necessary power. The current from this battery is interrupted by a hammer-break induction coil (to be distinguished through the trap) which also steps it up to the necessary voltage to break down the spark gap. Interruption for signalling purpose occurs by the Morse key mounted on the trap.

The only external connections are those to aerial and counterpoise. Regulation between primary and aerial circuit coupling and of the wavelength of these two circuits, is obtained by two handwheels, upon the side of the case not visible in the illustration, which may be simultaneously adjusted. In place of an aerial ammeter, a helium tube of much less weight, seen on the top of the case, serves to show resonance between excitation and aerial circuits.

The receiver is separate from the transmitter but mounted upon a common base-plate and is connected to aerial and counterpoise by means of plug sockets. Upon the receiver plate is a sliding inductance coil for tuning the aerial. In parallel to this are a detector and telephone, the latter being shunted by a blocking condenser.

The telephone is usually not a free instrument as shown in the illustration, but built into a silence helmet, as already described.

The total weight of the apparatus is about 25 kilograms.

The larger aeroplane station (Fig. 170) is not dependent upon batteries but is fed by an alternator geared to the aeroplane engine. This station radiates 0.1 kw. of energy. Its total weight, including the aerial, is from 40 to 50 kilograms and its range of 100 kilometres is quite sufficient for all ordinary scouting purposes.



FIG. 169.—Small aeroplane installation.



FIG. 170.—Large aeroplane installation.

[To face p. 354.]



FIG. 171.—Airship installation.
[To face p. 355.]

The small 500 frequency alternator working at 3000 revolutions per minute, is geared to the propeller shaft of the aeroplane, which itself works at roughly 1100 to 1200 revolutions per minute. A clutch is provided, so that the alternator is only running during transmission of telegrams and this can be controlled from the telegraphist's seat. This alternator delivers 0.2 kw. at 110 volts. It is excited by means of a small direct-current generator directly built upon the rotor. Regulation of output is obtained by means of a sliding field resistance.

The 110 volt alternating current is stepped up to 800 volts by a transformer and charges a single mica condenser whose capacity is appropriate to the aerial used. The spark gap is a small modification of the usual Quenched Gap type. As a primary inductance a flat copper spiral is used, whilst a variometer inductance, worked by a handwheel seen on the right side of the case serves to tune aerial to excitation circuit, under control of a small glow lamp seen to the left top corner, which gives maximum illumination during resonance.

The station is designed for use upon the 300, 450, and 600 metre waves, a common switch serving to make the necessary change in both circuits.

The receiver is built into the left part of the case where an upper pair of plug sockets for the detector and a lower pair for the telephones may be seen together with a sliding inductance for tuning purposes. A change-over switch in the right bottom corner serves to change the circuits from transmission to reception and vice versa. The receiver wave range is 300 to 900 metres. The telephone is of the helmet type.

The Airship Station.—This is a much larger station than the foregoing and is mounted in a light wooden cabinet, which is divided by a vertical partition into an open front and closed back section.

In the front half (Fig. 171) are all the separate parts of the transmitter and receiver needing adjustment during operation, while the back closed portion contains those parts of the apparatus, such as the transformer, inductance coils, and capacities, which do not need constant adjustment.

The aerial winch is mounted on four porcelain insulators on the top of the cabinet. On this winch a phosphor-bronze aerial wire of 3 millimetres diameter and 200 metres length is wound. The wire is wound off by means of an insulated hand crank to suit the wavelength chosen, the small indicator to be seen showing the length paid off. The

wire passes by insulated pulleys over the edge of the car and hangs freely. The crank, pawl, brake, and indicator and drum of the winch are all heavily insulated. Outside the cabinet on the right-hand side are the terminals for connection to the source of power and for lighting purposes. The dimensions of the cabinet are, width 60 cm., depth 33 cm., and height 76 cm., whilst with the winch the total height is 135 cm.

An aerial change-over switch in the cabinet is so arranged that when in the transmitting position all the receiver circuits are interrupted and vice versa, so that it is impossible to damage the receiving circuits during transmission by accidental pressure of the key. As a counterpoise the metallic portions of the vessel's gondola are used.

The source of power is an alternator with direct-coupled exciter, giving 0.5 kw. at 3000 revolutions per minute. This is driven either by the airship engine itself by means of a belt or chain gearing fitted with a throw-out clutch, or by a separate petrol engine as seen in Fig. 172 showing an actual installation upon a Zeppelin. To regulate this alternator a voltmeter and ammeter are installed in the apparatus cabinet.

The transmitter consists of an 8000 volt transformer in the left bottom corner of Fig. 171, the low-tension side of which is interrupted by the key which may be seen midway between the top and bottom of the right-hand side between the low-tension circuit fuses. This transformer feeds across the condenser of an excitation circuit of which only the spark gap is to be seen and the plug sockets for the 300, 800, and 1200 metre waves, the former being for use at low altitudes when only a moderate length of aerial can be unwound.

A receiver of the flat Universal type is also to be seen in the upper left-hand corner, and below this is a compartment for the separate variable condenser required for this receiver. Exact tuning, under control of a hot-wire ammeter, is obtained not by a variometer in the aerial circuit, but by winding off more or less aerial wire, which is accordingly calibrated in differently coloured lengths.

The effective range of this station, when working with a portable military station is 200 kilometres. The total weight is 275 lbs. of which the alternator contributes 120 lbs. It radiates about 0.3 kw. and therefore has the very high efficiency for a wireless transmitter of 60 per cent., impossible to obtain by any form of spark-transmitter, other than those employing some form of Quenched-Spark Gap.



(Wireless plant.)

(Generating plant.)

FIG. 172.—Interior of a Zeppelin showing wireless installation. [To face p. 356.]

WIRELESS TELEPHONY.

The progress in the development of wireless telephony for the use of aircraft has taken place entirely during the late war, and indeed only towards the end of the war, as may be realised when it is stated that, in actual fighting, telephony was not used upon the Allied aircraft and, as far as we know, upon the German aircraft. Furthermore, when it is stated that the modern range for wireless telephony between aircraft with absolute certainty is only four miles, it is easily realised that the subject is still only in its infancy.

Needless to say wireless telephony in aeronautics is only directly possible as a result of Meissner's observation that a thermionic valve can be utilised to generate the continuous wave oscillations necessary for wireless telephony. Previous to this observation, the only other methods of continuous wave production was by use of very large and expensive alternators of various types, or by means of arcs, neither method being in any degree applicable to aircraft.

Similarly, on the receiving side the substitution of a valve for any form of tickker and crystal detector, extremely sensitive to mechanical vibration, greatly assisted the general application of wireless to aeronautical purposes. Incidentally, one might mention that although during transmission a valve detector may be momentarily paralysed, it is self-restoring after a short interval. This is not the case with other forms of detectors similar to the crystal type, which, once rendered insensitive, do not return to a sensitive state until readjusted on a new crystal point.

One might even also say that aeronautical wireless telephony has only been rendered possible by the introduction of the hard valve, which eliminates all necessity for constant adjustment as occurs with the soft valve, requiring special training and attention impossible in practice on the part of the airman.

The advantages of the transmission of actual speech in place of Morse code, needing a considerable period of practice to acquire, and even then requiring either actual or subconscious translation, with consequent loss of time, is very great when telephony is used for artillery battery observation, upon such fleeting targets as a moving lorry transport or a rapidly submerging submarine.

As distinct from such observation work, wireless telephony has been actually used during air-raids on England in order to warn our aircraft of the approach of enemy aircraft, when transmission only occurred, however, from ground stations to the aircraft.

The methods adopted in wireless telephony have until quite

recently utilised a separate transmitter and receiver employing a common aerial, either instrument being inserted into the aerial at will by means of a switch. Such a method of speech is aptly compared by Eckersley to the use of a speaking tube, where only one person can speak at any instant, and speech is not therefore so rapidly understood as upon an ordinary telephone, where either person can listen or speak at will. Hence the advantage of some automatic duplex arrangement allowing either speaker to "break in" was soon recognised, and much attention has been devoted, particularly in our own Air Force, to evolve automatic duplex arrangements which require no switching arrangements.

The first wireless telephone aircraft, as far as the Allied side is concerned, was due to Prince of the R.A.F., in the summer of 1915. The arrangement used employed a trailing aerial of 250 feet length, utilised a wavelength of 300 metres, and had a total weight without accumulators of only 10 lbs.

This set was only a transmitter, speech being received upon the ground by retroaction. Although with an aerial current of 0.25 amp. ranges up to 100 miles were obtained, since the present-day hard valve had not appeared in England, great difficulties were experienced in maintaining constant conditions with the soft Round valve. The installation was very largely experimental, but served to form the basis of later work, facilitated by the introduction of hard French valve which became extensively used by our R.A.F.

The problems to be dealt with in aircraft wireless telephony are mainly four, namely:—

1. Purely electrical problems peculiar to wireless technology, such as the use of suitable valves, use of retroaction to generate oscillations, etc.
2. Difficulties common to both wireless and line telephony due to distortion of the transmitted speech. The complex air waves constituting speech, on analysis by the instrument cause varying energy intensities, some of which are more easily transmitted than others. Speech so becomes distorted and unintelligible, not owing to the energy dying away with increase of range, but merely owing to distortion effects. In practice it is found that for aircraft work a high-pitched singing voice is more advantageous than the lower-pitched voice of normal conversation.
3. The production of a sufficiently robust microphone, able to withstand severe vibration. Unlike ground telephony the results of using a sensitive microphone are disadvantageous, owing to external disturbances, such as mechanical vibration.

4. Problems of design common to all wireless apparatus for aircraft, such as elimination of unnecessary weight, restriction of actual size, simplicity of operation, etc.

5. Increased importance of the elimination of external noises since variations of speech can be more easily rendered unintelligible than Morse dots and dashes. These external noises may be due to the actual speech air-waves becoming mixed with air-waves due to the general uproar of wind and engine noise experienced in an aeroplane. These can only be overcome by increasing the relative value of the speech over disturbances, by speaking very loudly, and as near as possible, directly into the microphone. The actual speaking is difficult on physiological grounds alone, owing to the high wind pressure at high velocities, hindering actual muscular activity of the facial muscles. Again a further source of disturbance may be due to the production of ripples in the high-tension generator, nowadays employed instead of batteries to supply the plate circuit. These must be overcome by special design of the generator to eliminate ripples. Finally disturbance may be due to sparking at the various magnetto brushes on board, only overcome by enclosing the apparatus in metallic cases to the utmost possible extent, since it is a well-known fact that a closed metallic conductor has within it no magnetic or electrical fields due to outside fields.

When telephony is only required in one direction these problems become simplified; for example, if all the transmitting apparatus is to be on ground, the aircraft merely requires a suitable valve receiver, the problem becoming more complicated when speech is required from air to ground, and most complicated when speech is to be from aircraft to aircraft. In the latter case, in the R.A.F., in spite of no restrictions as regards expense, as compared to progress in commercial work where expense is necessarily restricted, the actual present-day range is as small as already mentioned.

The Application of the Microphone.—It is almost impossible to predict the behaviour of any particular microphone in the air from tests on the ground, since during flight even the character of the external vibration is completely changed. In general, up to a certain limit, the less the extreme sensitiveness of the microphone, the greater its suitability for air work. Such microphones have a great damping, and recently Furnival has patented a microphone with an adjustable damping.

The sensitiveness of the microphone is also modified owing to variation of the wind pressure on its diaphragm due to change

in the velocity and direction of the aircraft. In practice it is found that the best material for the diaphragm is mica or aluminium. A mica diaphragm acts similarly to the diaphragm of a gramophone, damping out all subsidiary vibrations, just as a gramophone diaphragm damps out all scratching noises due to the needle, and transmits only those vibrations due to the ridges on the record.

To apply the electrical variations resulting from speech directed upon the microphone diaphragm, there are two methods possible:—

1. The transmitter and receiver are extremely sharply tuned, so that any slight change of aerial resistance, due to variation by speech of the microphone's resistance (which is actually inserted in the aerial) will, since the resonance curve in each case is extremely steep, cause great variations of aerial damping and consequent extreme modification of aerial output and some change of wavelength.

Such microphones directly inserted in the aerial (Fig. 173 A) were used in the earliest telephony installations. By their use very great distortion of speech occurred, due to the sharpness of resonance, and this method is now nearly entirely abandoned.

2. Use of a more practicable, less sharply tuned transmitter and receiver in which the aerial current of the transmitter is not modified by a very small energy variation, as occurs in a microphone inserted directly in the aerial, but by the increase or reduction of aerial energy comparable in amount to the actual mean energy transmitted.

This method can be seen from Fig. 173 B, where instead of placing the microphone directly in the aerial it is placed in shunt across a suitable condenser in the aerial circuit, and variation of the aerial output is that due to variation of charge upon the condenser plates, due to the microphone currents.

As, however, these currents are still extremely small as compared to the actual aerial currents, owing to their relative energy values, a limit is soon reached to the accurate modification of the aerial currents.

If, however, before applying the microphone currents we first use a second valve (Fig. 175 C) to amplify them, we may make them comparable in magnitude to the actual aerial currents, so that, without very sharp tuning, the sensitiveness is very great. In practice it is found that not only does the control valve increase the microphone currents, but actually contributes to the aerial output.

This is the modern method used particularly in the R.A.F. transmitter. It is a simple step to arrange for the plate circuit of two valves to be supplied by a common high-tension battery or generator, similarly to supply both valve filaments from a common low-tension battery (Fig. 173 D). As in practice the

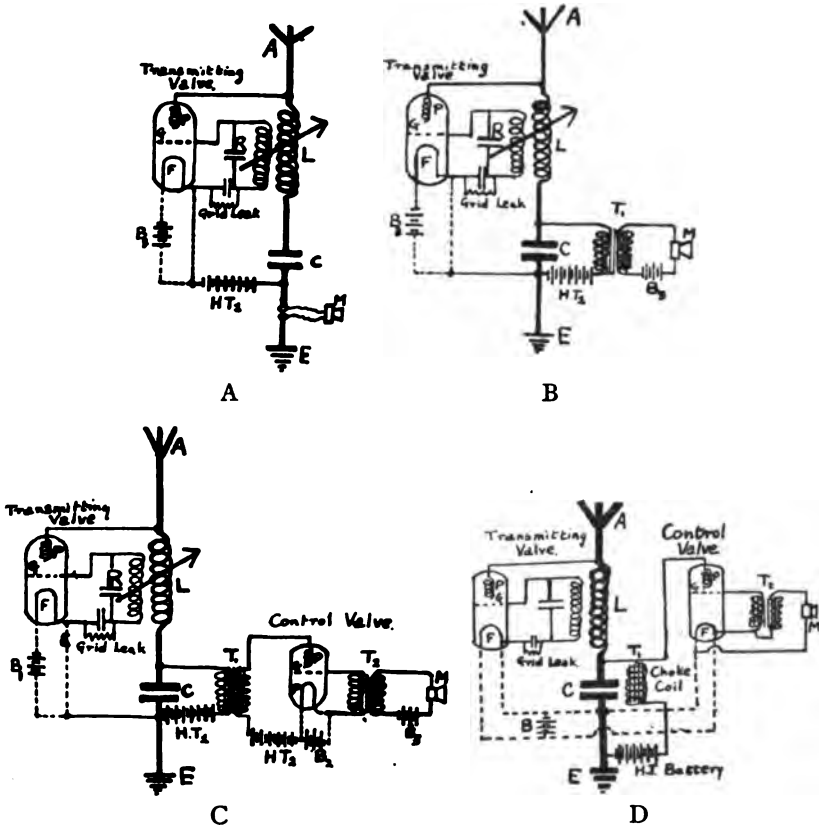


FIG. 173.—Application of microphone to valve transmitters (for aircraft).

transformer between control valve and aerial is replaced by a choke coil acting as a one-to-one transformer, this method is commonly known as that of "choke-coil control".

Other methods of control must be mentioned, namely, by modifying the transmitting valve's output by means of a microphone inserted via a transformer and, if necessary, a control valve, in the plate or grid circuits of the transmitting valve

(Fig. 174). In practice, however, these methods are not so practicable and have not been extensively used, although Round states grid control offers special advantages.

The actual connections of the R.A.F. Mark III transmitter are shown in Fig. 175 *a* and may be worked out.

This transmitter consumes 20 watts of energy, supplied from a high-tension generator giving 600 volts at 4000 r.p.m.

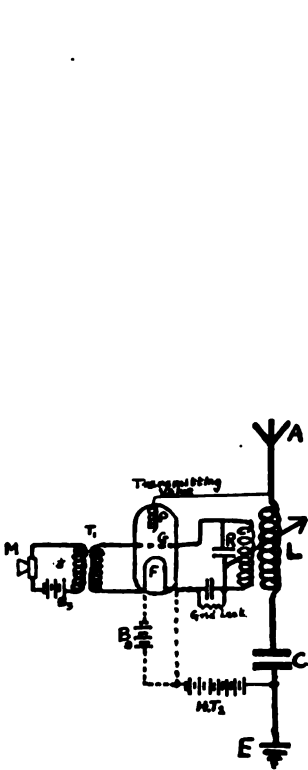


FIG. 174.—Grid control.

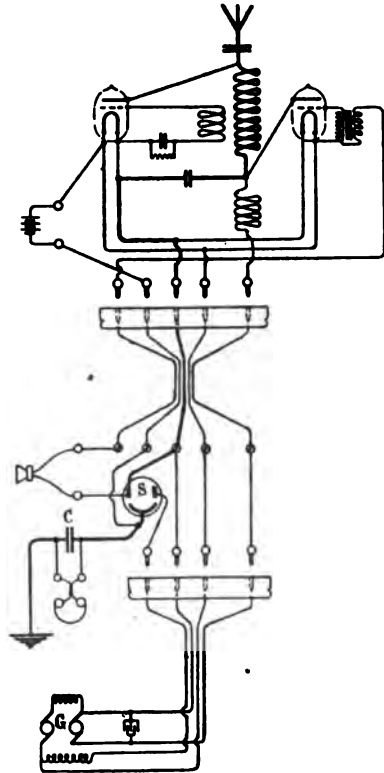


FIG. 175 *a*.—R.A.F. Mark III transmitter for telephony.

The voltage across the choke coil varied from 700 on no load to 300 to 400 volts on load. With a trailing aerial of 120 feet length and aerial current of 0.4 ampere, ranges of 4 miles from machine to machine were usually obtained and from machine to ground a range of 20 to 50 miles, the great increase being of course due to the superior facilities of reception at a ground station, with less interference and more efficient aerials.

In this R.A.F. instrument the actual installation was simplified by making the coupling to the aerial of the fixed direct type instead of being magnetic, and by designing the instrument

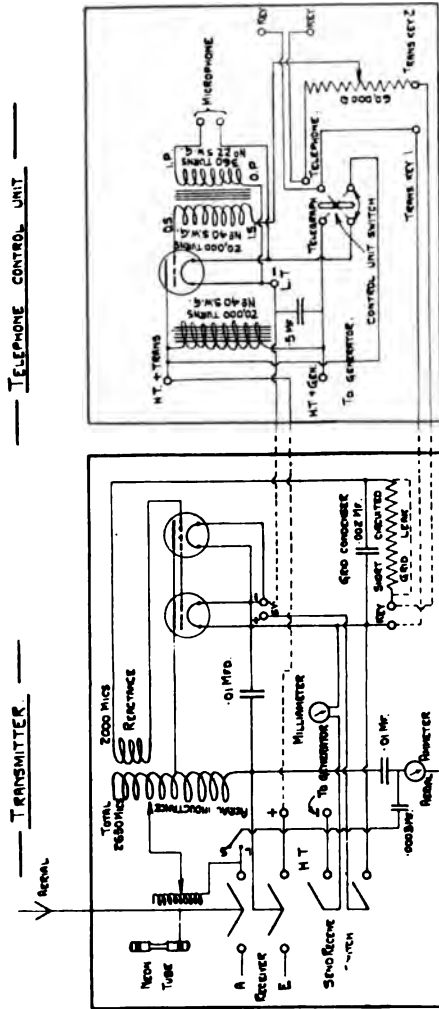


FIG. 175 b.—Arrangement of R.A.F. transmitter and telephone control.

for a fixed wavelength with a definite length of aerial. The reactance being similarly fixed there was no other transmitting adjustment except that obtained by a single switch which gave power to the plate and filament circuits. An aerial ammeter

was inserted, not for control, but to indicate that the instrument was in working order. Telephones connected across a small condenser C in the aerial allowed the speaker to hear his own speech, and so he was more confident that his set was working properly.

Whilst high-tension batteries were originally used for the plate circuits of this instrument, they were replaced on the introduction of suitable air-driven high-voltage direct-current generators, although the filament batteries were retained.

The bad effect of shaking upon the microphone was to a large extent eliminated by holding the microphone in the hand whilst actually speaking and not having it rigidly mounted upon the

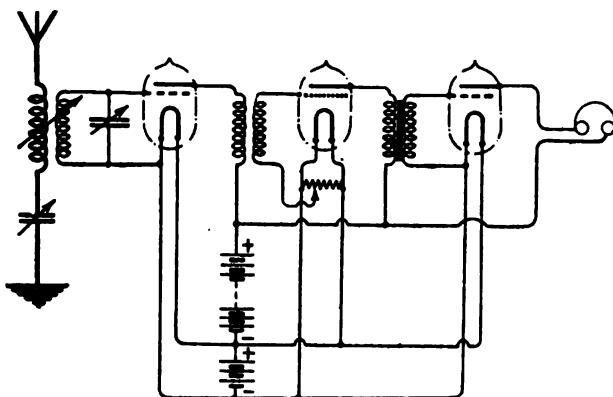


FIG. 176.—R.A.F. receiving system.

dashboard of the aeroplane. The microphone was of a heavily damped type.

Fig. 175 *b* shows the R.A.F. continuous wave transmitter, Type 57 C.W. This can be used for telegraphy or telephony, the microphone and its control valve being a separate unit, switched on or off according as to whether telegraphy or telephony is desired.

On the receiving side a normal 3-valve receiver was used, arranged as shown in Fig. 176. Here again all adjustments were eliminated, desired simplicity being obtained at the expense of range. The only adjustment was of the filament current which, whilst varying the electronic emission from the filaments and hence the sensitiveness, did not in any way vary the electrical constants of the receiving circuits so calling for readjustment, as is the case when the plate circuit is adjusted to ob-

tain any desired sensitiveness. This filament resistance took the form of a long resistance wire, mounted along the joystick and varied in length and resistance by means of a sliding contact.

At the end of the war a five-valve receiver was about to be introduced, two valves amplifying the high-frequency signals, one acting as a rectifier, and two acting as low-frequency amplifiers. This type of receiver overcame the difficulties of increase of disturbances with increase of weak signals and was ten times as sensitive for strong signals and thirty times as sensitive for weak signals as the previous three-valve instrument.

By this increase of sensitiveness it was possible to dispense with trailing aerials which are a great hindrance in air-fighting, and to use closed aerials around the wings, or fuselage, or both. Whilst such a closed aerial is less effective than a trailing aerial the advantage already mentioned is preferable to greater range, as when installed to facilitate manoeuvres in a fighting squadron, actual distance of range is not of very great importance, the formation of the squadron being such that machines are relatively close together.

Troubles of reception due to magneto-sparking were largely overcome by the instrument being nearly totally enclosed in a metallic case, with small mica windows so that the valves could be readily seen.

The whole installation was manufactured in units so that the transmitter could be used for ordinary Morse and, by switching in a separate unit, for telephony. The general lay-out has been already shown in Fig. 164.

Since no adjustments, except to change from sending to receiving and the adjustment of the receiving valves' filament current, were necessary, the different units could be installed as most convenient and these two controls be made remote from the actual instruments.

Duplex Aeronautical Telephony.—The disadvantages of a switching-over telephony set, such as just described, as compared to an automatic wireless telephone requiring no switch, have already been mentioned. To obtain this advantage extensive work was carried out by the R.A.F., notably by Eckersley.

We have already dealt with duplex working as applied to ordinary spark telegraphy (Chapter VIII.), but when we come to telephony the problem is somewhat different. It is obvious that whilst for spark work the most efficient and convenient way is, by means of a rapidly moving armature, to connect alternately

the aerial to receiver and transmitter, so eliminating difficulties of tuning (as obtained by use of two aerials with a common earth), this method is not applicable to telephony since a continuous state of oscillation is being dealt with and not a sequence of wave-trains, which if they become somewhat clipped are not rendered unintelligible for Morse reading.

Whilst only the tuned aerial system, which for spark work gives great inefficiency, is applicable to telephony apparatus, fortunately for telephony this inefficiency is very greatly reduced since continuous wave oscillations being capable of extremely sharp tuning (unlike spark-discharge damped oscillations which are relatively flatly tuned), a very slight difference of wavelength between two paths will ensure a more efficient separation of energy of two slightly different wavelengths.

Before we deal with the more practical aspects of duplex work, we may mention various ways which have been suggested.

One method is by the use of two aerials spaced at right angles more than a quarter wavelength apart, one for transmission and one for reception. This spacing obviously renders such a method inapplicable to aircraft.

An Artom frame aerial arrangement has also been suggested so that the effects of the near transmitting frame upon the two limbs of the receiver frame balance out. Such a method is purely hypothetical.

Alexanderson has used a balanced aerial method as described on p. 208, but this again is not possible on aircraft since they cannot carry two perfectly rigid aerials.

There remain three other methods, all of which have been tried in actual practice.

One method is known as the "quiescent" aerial method. Here the aerial is not set into oscillation until the microphone is spoken into, when the transmitting valve is caused to oscillate, the receiver being meanwhile protected against the large transmitting currents.

This method has the great advantage that it only requires a single aerial and a single wavelength for both transmission and reception, but on the other hand, during transmission the receiver valve is paralysed owing to the potential of the grid of the receiving valve becoming too high. As this potential, even with a fairly low resistance leak, requires an appreciable time to leak away, the receiving valve is not immediately ready for work. So, after speaking, it is impossible to immediately receive speech from the opposite station.

Such a method is not therefore really a duplex arrangement, and whilst it has the advantage over any switching system that it avoids the use of a change-over switch, it has perhaps a greater disadvantage to this method in that it involves very great shielding of the receiver and so greatly complicates the installation, an undesirable feature in aircraft installations.

This method has been somewhat modified and simplified by arranging that the transmitter is not truly quiescent, but is always slightly oscillating. When during speech the microphone is actuated the aerial output is greatly increased.

Over a long range, where the small energy permanent oscillations are very little or not at all received, this augmentation of output due to speech will alone be heard at the receiving end.

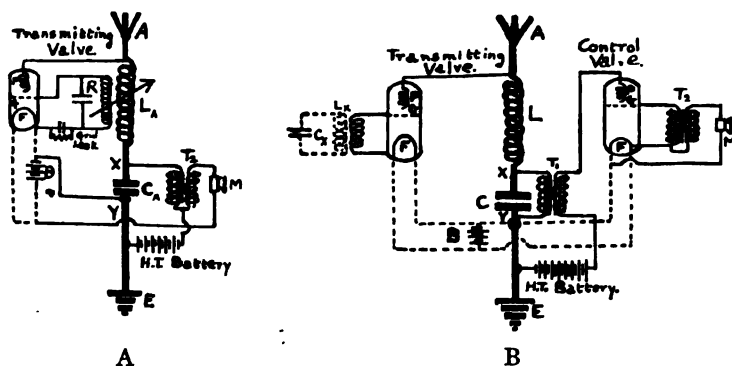


FIG. 177.—“Augmented oscillation” transmitters for duplex working.

For a short range, however, the method is not effective since then the permanent oscillation is always considerable at the receiving end and any variation of output during speech is not readily appreciable.

This method known as the “augmented oscillation” method was first proposed by the American G.E.C. but also independently in our own Air Force. The method can be seen from Fig. 177 A, where the high-tension supply is arranged across the points X and Y. Speech into the microphone M causes, through the transformer T₂, an appreciable increase of potential across X and Y so that the previously feebly oscillating transmitting valve is set into strong oscillation.

The method may be further improved by first amplifying the microphone currents before applying them to the transmitting valve by means of a control valve, as shown in Fig. 177 B,

so that a more advantageous relation of control to transmitting energy is obtained.

In practice it was found that as soon as this second control valve was applied, a valve transmitter, which had previously given very good speech, now gave bad speech. It was found the application of a small permanent voltage to the transformer immediately gave good speech again.

Various theories have been suggested to explain this. One supposes the relation of the voltage across the transformer and the aerial current to be a straight line function but not a line passing through the origin. Hence, to obtain a direct relation of transformer voltage and current in the aerial, it is necessary to first supply a steady voltage. Otherwise the voltage supplied by actual speech has first to supply that necessary to obtain the straight line relation, a condition very analogous to the necessity of supplying a permanent steady e.m.f. to certain crystal detectors already dealt with. Since different tones of the voice have different energy values and therefore give different transformer voltages, the subtraction of a constant voltage value from each to reach the ascending line, causes them to change their relative value to each other. So speech becomes mutilated on radiation and reception.

It has also been suggested by Lea that the power output to the choke coil was not directly proportional to the voltage input but was proportional to the square of voltage input. Hence voltages due to the transformer of 2, 3, and 4 would represent 4, 9, and 16 times the aerial output. If on reception any particular sound waves constituting a sound had these previous relations, since the same law does not hold as regards their conversion back to speech; the speech would be mutilated. It is not evident how this would be improved by application of a permanent voltage.

The most likely explanation appears to be that a measurable time lag occurs between the application of the voltage at the transformer terminals and the appearance of energy in the aerial circuit, owing to the very small but appreciable time taken for the establishment of the various inductive fields.

For a small applied transformer voltage this time is practically as long as the time to establish fields due to more powerful applied voltages. These differences of field establishment being due to the relative energy values of different sounds, the electrical representation of speech radiated from the aerial will have slightly different time relations to the actual speech applied to the microphone.

If, however, we apply a small constant voltage to the transformer there will always be a certain establishment of field in the aerial circuit capable of much more rapid modification by the applied transformer voltages due to speech, and so the time lags for different speech sounds will be more equalised.

Eckersley has overcome this defect by applying a continuous excitation to the power valve grid by means of an external source, represented in Fig. 177 B by dotted lines, and has obtained improved speech. In this case, however, it was found the aerial was not truly quiescent but always oscillating to a small extent, the improvement in speech being lost if this oscillatory state was prevented.

In general we may say that the quiescent valve method is inferior to other methods about to be described in so far that this lag effect occurs. Even if this is overcome by the method just mentioned, an appreciable time after speech elapses before the oscillatory condition dies out so that reception is not immediately possible. They also require special troublesome complication of the receiver to protect it from the effect of this continuous oscillatory state of the aerial.

The remaining two methods have a certain similarity and give a true duplex effect in so far that there is no time lag and the receiver is therefore always ready for reception immediately transmission ceases.

In one method two aerials are used of different wavelength, one aerial being for transmission and one for reception, preferably separated as far as circumstances on aircraft permit.

The transmitter is of any normal type, but the aerial of the receiver is split into two paths to earth (Fig. 178), one being practically all capacity C_1 and the other both inductance L_2 and capacity C_2 . If C_1 is much greater than C_2 the impedance of the capacity limb will be much smaller than the impedance of the second limb L_2C_2 . Any strong forced oscillation of different wavelength, due to the near transmitter aerial, will divide along the two paths inversely as their impedances. So the majority of the forced oscillation will pass to earth via the capacity limb.

On the other hand any received oscillation from a remote aerial tuned exactly to the receiving aerial will not divide inversely as the impedances, but will largely pass via the tuned limb L_2C_2 . If a receiver is coupled to the inductance L_2 , incoming signals will be so heard.

In the case of the mistuned forced oscillation due to the

near transmitter a certain proportion of the energy of small magnitude ($\frac{1}{20}$) will pass via L_2C_2 . This will not be of very great intensity and will allow the speaker to hear his own speech during transmission, an effect not only to be desired but even specially arranged for in the R.A.F. instrument already described.

For this method to work effectively the transmitted and received wavelengths should differ by 20 per cent.

The dual aerial required by this method was illustrated for an aeroplane and airship in Fig. 167 E and F.

In practice it is found that it is necessary to earth both transmitter and receiver aerial at a common point, not separated by any long lead through either instrument.

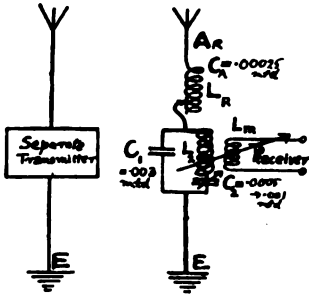


FIG. 178.—Duplex arrangement (two aerials two wavelengths).

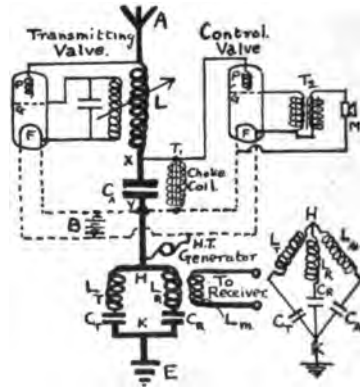


FIG. 179.—Divided earth duplex arrangement (one aerial two wavelengths).

The remaining method is known as the Divided Earth Method. Unlike the former method only a single aerial is required, but two wavelengths are still necessary.

The earth of the transmitter is divided at a point H into two parallel paths. In one arm, inductance L_T and capacity C_T is inserted, to give, *without any of the aerial circuit*, the desired wavelength for transmission.

In the other arm inductance L_R and capacity C_R is inserted to give, with the common part of the aerial, the desired wavelength for reception, which necessarily differs from that for transmission.

As in the previous method the receiver is coupled to the inductance L_R of the receiver arm, by the inductance L_m .

The common point H is made a node of potential by making the wavelength of the transmitting arm equal to that of the

aerial without the split path I, in which case the aerial and transmitting arm may be regarded as forming an alternating current bridge having the points H and K at a common potential across which the receiving arm is connected as indicated in the small diagonal of Fig. 179.

With this arrangement there is no tendency for current to be forced into the receiver arm (since the points H and K are at a common potential) when the transmitting valve is caused to oscillate sharply in tune with the aerial and the transmitting arm having equal wavelength.

In practice it is very difficult to obtain exactly this nodal point, largely because the aerial wire and hence its wavelength will vary with its position relative to the aeroplane.

By making L_T small and C_T large the arrangement also partakes of the previous method described, that is, the transmitting arm impedance is very small relatively to the receiving arm and forced oscillations will largely go to earth via the former, whilst the small amount of energy passing into the receiver arm will allow the speaker to hear his own voice.

With this arrangement for aerial currents up to half an ampere, the wavelengths need only vary by 20 per cent., or, if tuned stoppers are used only 10 per cent.

With both methods just described there is the advantage that standard transmitters and receivers can be used, the duplex apparatus being mounted as an accessory. Only the former method has been actually tried in the air although both have been used on the ground.

With all methods employing two wavelengths it is necessary that both these two wavelengths should be the same with instruments having fixed wavelength as in aircraft. The best arrangements to avoid confusion, as suggested by Eckersley, is for all aircraft to send on one wavelength and all ground stations send on the other.

This would mean that aircraft could not talk to each other. Greater facilities at a ground station would allow the latter to intercommunicate by change of wavelength.

The use of two wavelengths to work between two definite stations does not jam other stations any more than by use of a single wavelength for both reception and transmission, since each wavelength is only utilised half the time with two wave lengths as compared to the time with one wavelength.

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CHAPTER XIII.

CONTINUOUS WAVE TELEGRAPHY AND TELEPHONY.

THE extended use of continuous wave transmitters for actual practical purposes has only developed during the last six years, i.e. since the inception of valve transmitters.

As continuous wave generators permit the transmission of human speech by wireless means, since the earliest history of modern radio-telegraphy, attempts have been made with more or less success to produce continuous wave generators, and so to obtain the great advantages which telephony offers over telegraphy, the former permitting a more rapid transmission of thought and eliminating the necessity of knowledge of some code as Morse.

Amongst the very earliest attempts were those of E. Ruhmer, whose original methods were based upon the modification of light beams of arc lamps and their detection by selenium cells. This photophone method, whilst marking an epoch in general wireless history did not have any extended use. It is obviously restricted in range, by the comparatively small range which it is possible to obtain with the most powerful searchlights (projectors).

Ruhmer's experiments may be found in his book "Wireless Telephony" which has been translated into English by Dr. Erskine Murray.

Until recent years wireless telephony was of such small importance, as compared to wireless telegraphy, that it became the general custom in wireless books to regulate it to the last chapter. It is noticeable that from the publication of Ruhmer's book in 1907, no other important book appeared until 1918, when the excellent book by Goldsmith was published in the United States.

In spite of its growing importance, the restriction upon size of the present book on general wireless, makes it impossible to devote more than a single chapter to continuous wave generators, which are particularly used for telephony. In such a space an outline only of the most important advances and methods of

attack of the problem can be given. Volumes could, however, be written upon continuous wave work and telephony, and those requiring further information can only be referred to Goldsmith's book already mentioned, and to Coursey's "Telephony without Wires". The latter, however, is rather difficult to the uninitiated, since it also deals with purely spark apparatus for telegraphy only, without specifying it as such.

It should also be particularly noted that continuous wave working is not synonymous with wireless telephony, and perhaps at the present day continuous wave transmitters are used more for telegraphy than for telephony.

For telegraphy itself two methods are generally used. One, in which an uninterrupted continuous wave train is evolved, which by means of a suitable "tickker" or by "beat reception" is converted to audible frequencies at the receiving station. With the other method, known as "interrupted continuous wave" (or more briefly as "I.C.W."), the continuous oscillations are cut up at the transmitting station into a series of oscillations of audible frequency, and is therefore audible to all other stations, whether designed for spark or continuous wave working.

With continuous wave work of recent years practice has shown, for a number of reasons, that for equal transmitting power, continuous wave signals can be heard at much greater ranges than spark-discharge signals. It must, however, be again borne in mind that such increased range, however, only refers to telegraphic signals. When continuous waves are used for telephony the working range is very much decreased and is lower than the normal spark range, since not only has the receiving ear to respond to periods of transmitting aerial oscillation, but also to modulations of intensity. This so necessitates a much greater receiving station intensity.

There are, for the production of continuous wave oscillations for either telegraphy or telephony, five chief methods, namely:—

- (1) by arc-generators,
- (2) by rapid sparks of the quenched type, the wave trains being caused to overlap, and so to simulate pure continuous waves,
- (3) by special high-frequency alternators,
- (4) by static frequency-doublers, either magnetic, or depending on special rectifiers,
- (5) by thermionic valves.

The first method is the oldest method, and the last the most recent. The second and third methods were developed almost simultaneously, and previous to the fourth method.

It will be most convenient to deal with each class of generator separately, before dealing with purely telephonic questions.

ARC-GENERATORS.

In 1899 Mr. W. Duddell found that if a direct-current electric arc, such as that of an arc-lamp, is shunted by a circuit containing capacity C and inductance L (Fig. 180), oscillations of a frequency, approximately $\frac{1}{2\pi\sqrt{LC}}$, occur in the shunt circuit.

The production of these oscillations is as follows:—

On closing the shunt circuit, the flow into the condenser causes a drop in the flow of current into the arc. Consequently the temperature falls, and the resistance of the arc increases, becoming a greater fraction of the resistance of the main circuit. The resistance of the main circuit and the

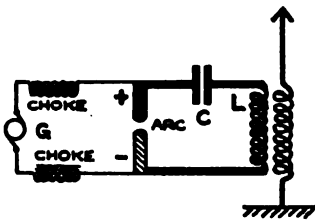


FIG. 180.—Duddell arc.

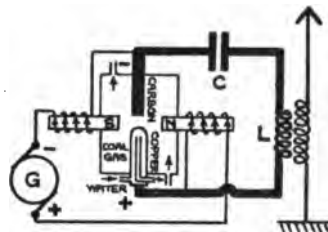


FIG. 181.—Poulsen arc.

difference of potential between the arc carbons rises with a further production of flow into the condenser. Eventually the accumulation of charge in the condenser raises the difference of potential between its plates to that between the carbons. This results in stopping the flow into the condenser, and the arc regains its original condition. When the current via the arc has risen to its original value, its resistance falls, and in consequence the potential across the arc falls. The condenser then begins to discharge across the arc, so reversing the previous condition.

The inductance in the shunt circuit gives this circuit inertia, so that the current having started, the circuit is always carried past the stable condition and oscillations occur. The existence of the oscillation depends upon the fact that the resistance of the arc varies with the current in such a manner that the potential difference between the carbons diminishes with increasing current, and the arc behaves as though it had a negative resistance.

This is the condition for the simple Duddell singing arc, but Barkhausen and Blondel have shown that three conditions may occur :—

1. The Duddell singing arc, where the oscillating current is very much less than that through the arc, and the arc is permanently established.

2. The Poulsen arc, when the oscillating current is so large that the arc is entirely extinguished. As the oscillating and arc currents again become equal, the oscillatory discharge voltage having fallen, the arc is re-established and again boosts up the oscillatory circuit.

3. An extreme case in which the arc is extinguished and then re-established in the reverse direction opposite to the steady current. This occurs in ordinary open spark discharge circuits, when continually reversed surges occur back and fro. To a much less degree it occurs with Quenched-Sparks, but is soon prevented by the quenching effect.

In the Duddell arc since the oscillating energy is only small compared to the arc energy, the method is only applicable to wireless telegraphy at the expense of efficiency.

Poulsen found in 1903 that, by enclosing the arc in hydrogen (or in practice the hydrocarbons present in coal-gas) and providing an intense magnetic field at right angles to the arc in order to extinguish it (Fig. 181), the consumption of energy by arc formation was greatly reduced and a greater output of oscillatory energy was obtained.

The action of the hydrocarbon atmosphere is to prevent oxidation of the electrodes. Choke coils are inserted in the arc circuit to prevent the high-frequency energy from surging back into the windings of the machine supplying the direct current to the arc.

Poulsen also found the best results were obtained if the positive arc electrode was made of a hollow copper tube and water cooled.

This method of production of oscillatory energy for wireless purposes has been greatly developed by Poulsen in conjunction with Pedersen and applied to commercial radio-telegraphy. It has been used largely in the United States, up to powers of 100 kw., with which transmission over 2100 miles between San Francisco and Honolulu has been established. Smaller sets of 30 kw. have been installed at various places by the U.S.A. Navy and 12 kw. and 5 kw. sets are made for ship sets.

A small station of this type is shown in Fig. 182, where the





FIG. 182.—Poulsen arc generator.

[See p. 376.]



FIG. 183.—Telefunken series-arc.

[To face p. 377.]

most noticeable features are the large electro-magnet coils already mentioned. Above them is seen the arc chamber, and in front a motor for rotating the carbon electrode is also seen.

One example of the Poulsen arc was present at Cullercoats in Great Britain, but has, of recent years, been replaced by a spark installation. The recent report of the Parliamentary Select Committee upon Radio-telegraphy, has recommended the adoption of Poulsen arc transmitters for the new British Imperial Scheme, a procedure, however, which the critics of the arc method expect to prove difficult in practice.

Next to the spark transmitters of the Telefunken and Marconi Companies and excluding Government systems, the Poulsen System is perhaps the most important. It has the advantage over the spark method that :—

1. It is applicable to telephony as well as telegraphy.
2. Continuous wave transmitters for equal aerial power give greater ranges than damped-train spark transmitters. With the very high efficiency of the Quenched-Spark this advantage is however neutralised.

Against these advantages must be set the disadvantages :—

1. Very much more complicated apparatus is necessary, particularly for regulating the feeding of the carbon electrode, than even with the Marconi disc-discharger and far more complicated than with the true Quenched Gap.
2. The necessity of water cooling and some form of hydrocarbon in default of hydrogen, would render its use prohibitive, in out-of-the-way tropical stations, where a cheap source of gas is not available.

As regards the efficiency of the arc transmitter as compared to the Quenched Gap, it is typical that from 1906-1909 the arc method was adopted and abandoned by the Telefunken Company, in favour of the Quenched Gap.

The Telefunken arc method did not, however, use a magnetic field to quench the arc, nor a hydrocarbon atmosphere. To increase the oscillating energy a number of arcs were used in series (Fig. 183), the negative electrodes being formed by solid carbon rods and the positive electrodes of upright copper tubes cooled by water and recessed at their lower end to take the hemispherical carbons. Either carbon could be moved up and down independently or the whole battery moved together (by the handle seen), in order to strike the arc at the commencement of transmission. The atmosphere of carbon dioxide formed by the oxidation of the carbon electrodes and retained by the hemi-

spherically hollowed copper electrodes, was stated to perform the same function as the hydrocarbon of the Poulsen arc.

The sets were manufactured with 6 arcs for a 220 volt direct current supply, 12 arcs for 440 volts, and 24 arcs for 880 volts. With 24 arcs in series, and energy consumption of 6 kw. only about 10 per cent. of the energy was radiated from the aerial. On the other hand, as compared to the Poulsen arc, the apparatus was much simplified, needed less adjustment, and the carbon electrodes had a much longer life of 200 hours per half-inch length.

A typical Telefunken arc transmitter is shown in Fig. 184.

In 1907 with such a transmitter of 2.5 kw. power and a microphone directly in the aerial, a telephonic range of 75 km. was obtained, this then being the longest radio-telephony range but was exceeded during the next year by Poulsen.

In 1908 a new arc transmitter due to Colin and Jeance was tried by the French Navy. This transmitter employed three arcs in series, but was original in having an intermediate circuit between the arc and aerial circuits. The arcs were very like those of the Telefunken Company in their shape, but were surrounded by an hydrocarbon atmosphere. With such transmitters ranges up to 200 km. were obtained. For details of the actual apparatus Goldsmith should be consulted.

In Italy Majorana using the Poulsen arc and a particular form of microphone of his own construction, obtained, in 1908, ranges for telephony up to 400 km.

In modified form the Poulsen arc has also been largely used by the Lorentz, and the Berliner-Poulsen Companies in Germany and the Federal-Poulsen Company in the United States. Space does not permit of the description in detail of the modified Poulsen arcs used by these companies, the later of which achieved the range of 2100 miles already mentioned.

RADIO-FREQUENCY SPARK-TRANSMITTERS.

It has been already stated that according to Barkhausen and Blondel's classification the third class of arc generators tend to ordinary spark-transmitters, the arc being periodically extinguished.

The transition from arc to spark radio generators is therefore a gradual one, which may be appreciated if it is mentioned that in the two standard books on telephony we find Goldsmith classifies methods due to Ruhmer, Dubilier, Morreti, the Japanese

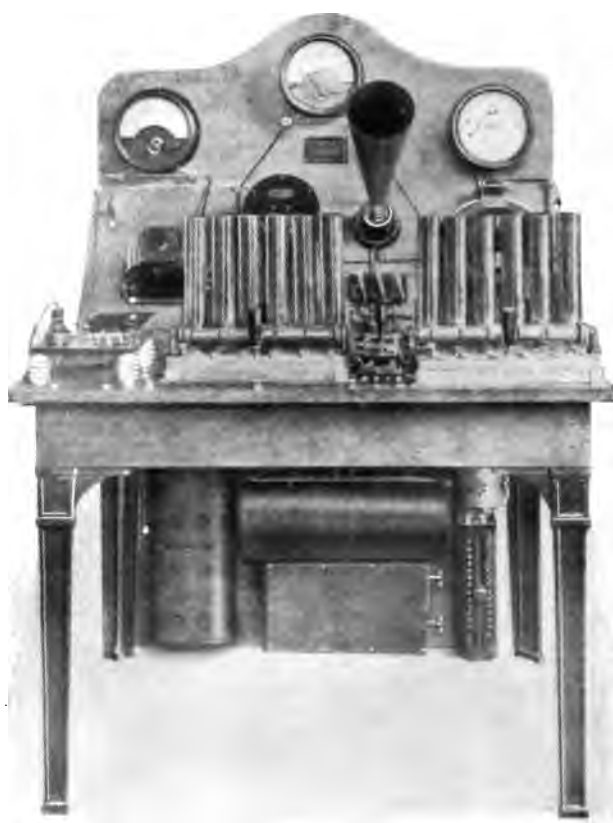


FIG. 184.—Telefunken arc set (1906).
[To face p. 378.]



T.Y.K. system, and Dwyer as spark methods, whilst Coursey regards them as arc methods.

From Chapter II. of this book we have seen that, with a Quenched Gap, we may consider the effect upon the aerial of the passage of successive sparks as represented by Fig. 185 *a*.

Such spark excited aeriels are unsuitable for telephony, in so far that during the intervals of no radiation, no modulation of the radiated energy by the voice can occur.

It is obvious on theoretical grounds, if, by suitable increase of alternator frequency, or otherwise, we cause a more rapid rate of sparking, we may hope to produce a new spark train before the preceding one has died out, which if the excitation circuit is quenched will take an appreciable time. Our aerial oscillation will then take the form of Fig. 185 *b*.

The aerial may so be regarded as excited by continuous

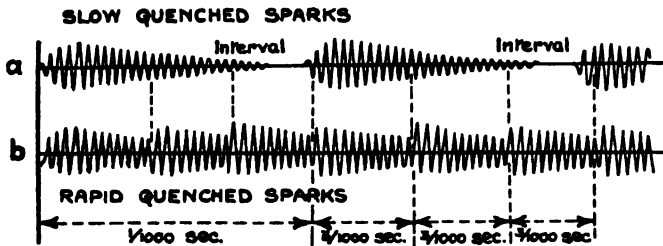


FIG. 185.

waves, although strictly speaking the radiation will not have a strictly constant amplitude of oscillation, as occurs with true continuous wave generators. It will, however, be possible to modify this radiation in order to transmit speech.

Amongst the earliest attempts in producing continuous oscillations by spark discharge was that of Ruhmer, who formed his spark gap of two moving metallic bands passing around triangular water-cooled surfaces. Spark (or arc) formation occurred between the bands, whilst passing around the apices of the cooling arrangements. The movement of the bands, ensured the presentation of cooled and clean electrode surfaces, giving a regular discharge.

The best-known spark method as applied to telephony is that of Lepel. The Lepel spark gap very closely resembles the Telefunken Gap, consisting of metal disc electrodes, but separated by paper instead of mica rings. Considerable controversy has

arisen between Lepel and the Telefunken Company regarding priority in the use of such gaps, regarding which the "Electrician" of 1911 should be consulted.

The paper disc of the Lepel Gap gradually burns away, so producing an atmosphere of carbon dioxide which is said to promote the arc formation which undoubtedly occurs. As with arc transmitters a direct current supply is usually adopted, but sometimes an alternating supply of moderately high frequency is used.

The method of connection is similar to that of the Poulsen arc, if we consider the aerial as direct-coupled across the gap, one plate of which is connected to the aerial and one plate to earth, Fig. 186. After quenching of the spark we have a common aerial, and shunted excitation circuit, as indicated by the arrows,

of low damping since the spark gap is then eliminated. To assist rapid quenching, aerial and excitation circuits are slightly mistuned.

The Lepel system has been somewhat developed in France, but has not had any great commercial success, the International List of 1913 only showing one land and one ship station on this system. The transmitter can be used both for telegraphy and telephony.

Another Quenched Gap which has been used for continuous wave production is that of Chaffee, evolved in America.

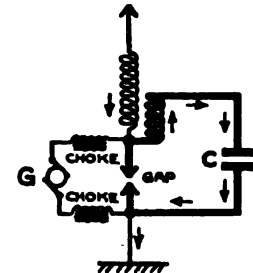


FIG. 186.—Lepel transmitter.

This gap consists of an aluminium and a copper electrode of about 2-square centimetres area. As with the Poulsen arc method, an atmosphere of some hydrocarbon, due to the combustion of alcohol, encloses the gap. Flanges are provided to radiate the heat due to sparking, and by means of insulated handles the spark length can be varied. Later forms have one electrode mounted upon a diaphragm.

Lieutenant Ditcham in England, during 1912, used a gap very similar to that of Chaffee, to produce continuous oscillations for telephony and was able to conduct telephony, first between Letchworth and Northampton, and then to ranges up to 100 miles.

In both the Chaffee and Ditcham Gaps as with the Lepel and Telefunken Gaps, it was found advisable, to promote good quenching, to somewhat mistune the aerial and excitation circuits, in a ratio of aerial to excitation circuit, tuning varying from 1.51 to 1.71.

The Japanese T.Y.K. system for telephony, which up to small powers has had considerable success in Japan for ship and shore stations, employs a rapid series of sparks between electrodes of magnetite and brass, the discharge tending to arc formation. This method employs an automatic device to separate the electrodes after sparking or arcing has once commenced.

Dubilier, in 1911, used a Quenched Gap for telephony, one electrode of which was rotated. The Lorentz Company in Germany have also, both for telephony and telegraphy, used a Quenched Gap, with which the cooling and quenching effect is obtained by the use of one hemispherical electrode which fits into a concentric cup electrode, an hydrocarbon atmosphere being provided between the two electrodes by the combustion of alcohol by the spark discharge.

Distinct from the above forms of spark gaps which tend towards arc formation, generally using an hydrocarbon atmosphere, we have the method used in America with great success by De Forest. Here the spark frequency was increased by use of a 3000 cycle alternator, so giving a rate of sparking of 6000 per second, as compared to the 1000 per second spark rate with the Telefunken telegraphy gap. Telephonic ranges up to 160 km. were obtained with these installations which were fitted upon expresses of the Delaware, Lackawanna, and Western railroad.

Quite a different method of increasing the rate of sparking has been employed, first by Galletti and in a modified form by Marconi.

Galletti's method consists essentially of the arrangement of a number of excitation circuits, each with a separate spark gap, in parallel across a common low-tension supply circuit and a common aerial. The excitation circuits are caused to rapidly discharge in series, the timing of the discharge being stated to be governed by the insertion of a suitable resistance in each circuit.

Marconi, in 1912, extended this method, by utilising his disc discharger in place of resistances in order to cause timing of the discharge.

A number of disc dischargers are arranged upon a common shaft, but with the electrode of adjacent discs regularly displaced, so that their envelope develops a spiral around the longitudinal axis.

The most interesting feature of this patent, taken out after the Telefunken-Marconi Patent Agreement, is the inclusion in each excitation circuit of a Quenched-Spark Gap S_1 - S_4 (Fig. 187)

in order to produce rapid quenching. It is obvious if the rotating disc dischargers D_1 - D_4 produce a quenching effect, as often stated, the inclusion of such quenched gaps would be entirely unnecessary.

Large continuous wave plant of this type has been installed by the Marconi Company at Carnarvon, and has given practical results. Owing to its complication, however, it is unlikely to have any great application for land stations, when easier methods of continuous wave generation are available, and it is impracticable for ship stations.

The remaining method of utilising spark dischargers for continuous wave production depends upon increasing the phases, instead of the frequency, of the alternator supplying the excitation

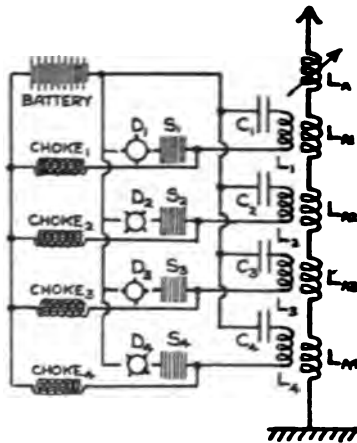


FIG. 187.—Marconi's high-frequency generator.

circuit. For each phase the spark gap breaks down twice, as with a single-phase alternator. With a 3-phase alternator, however, six sparks are obtained as compared to two sparks with a single-phase alternator.

This method was first proposed by Eisenstein in 1906, who used three non-quenching open spark gaps, exciting a common aerial. Little practical results were obtained, however, until Gage used quenched gaps with a 3-phase 4000 cycle alternator, so that the number of discharges per second was $3 \times 8000 = 24,000$.

There is no limit to the number of phases which may theoretically be used, so that with a 9-phase alternator of the comparatively low frequency of 5000 (as compared to true high-frequency alternators) the spark rate would be 90,000 per second.

Expense of construction of alternators and transformers would, however, limit the application of this method to large land stations.

Various patents have been taken out for spark gaps, of which the electrodes are formed by mercury in an atmosphere of mercury vapour. In practice these forms of dischargers have not been commercially used. Amongst those whose names must be mentioned in this connection are Cooper-Hewitt, Liebowitz, and Vreeland.

Marconi has in a patent specification applied his disc discharger to time the discharge of such mercury vapour gaps.

HIGH-FREQUENCY ALTERNATORS.

The fundamental relation in the propagation of alternating current effects along wires is, $n\lambda$ equals the velocity of light (3×10^8 metres per second). With ordinary alternators n is small, being in the neighbourhood of 100 and λ correspondingly great, so that it is practically impossible to build an aerial of sufficiently great capacity and inductance to cause radiation of energy as necessary for wireless transmission.

If, however, we make n sufficiently large λ decreases. At a frequency of 100,000 the wavelength becomes 3000 metres which with large aerials can be efficiently radiated.

To increase the frequency of any alternator we can either :—

- (1) increase the number of poles upon the rotor, or
- (2) increase the velocity of the rotor, so that the rate of rotor poles passing any field coil in unit time is increased.

Both these methods, as soon as they are applied in practice produce difficulties, preventing their general adoption.

If we increase the number of poles, since the rotor must be kept within rational dimensions, the poles must be made very small and incapable of carrying great energy. Furthermore, owing to the non-penetration of rapidly alternating magnetic fields into the magnetic medium, the lamination must be very thorough in order to reduce hysteresis losses. This entails the highest degree of lamination of very thin soft iron sheets with thin paper, and the pole soon becomes very largely non-rigid paper and therefore incapable, with safety, of rapid rotation.

When alternately we endeavour to increase the speed of revolution of the rotor, further difficulties arise, such as the necessity with a very small air gap between stator and rotor, of very constant adjustment of alignment at high speeds, difficulties of

lubrication of bearings, and in the event of any breakdown very great danger to personnel, owing to the high peripheral speeds.

In spite of these difficulties, attempts have been made from time to time to construct alternators capable of directly generating high-frequency energy. In general, all such alternators are of the inductor type, as described in Chapter III. for the much lower frequency of 500.

The best-known attempts are those of Alexanderson of the American General Electric Company, undertaken at the instance of Fessenden.

The first of these machines, constructed in 1907, delivered 1 kw. of energy. Shortly after a 2 kw. machine was constructed and used in actual practice.

These machines had automatic devices to stop the machine should lubrication be defective and a rise in temperature of the bearings occur. Also special arrangements were adopted to automatically neutralise expansion of the rotor shaft to ensure correct alignment. The frequency obtained was 100,000 cycles.

Most books on wireless telegraphy will be found to give detailed descriptions of such alternators, whose uses, owing to their small energy output, have been very limited. More recently Alexanderson has manufactured 50 kw. machines of 50,000 cycles, and still higher outputs are proposed. In order to overcome insulation difficulties, the energy is delivered at low voltage and raised by static transformers, before its application to the aerial circuit.

Whilst such machines have been successfully used in America by Fessenden, more easy methods of continuous wave generation limit their general adoption. Their use has been very largely experimental, and is hardly likely to develop since owing to the very high peripheral speed some danger would always attend their use in the hands of the unskilled.

Bethenod and Girardine have proposed methods of designing the teeth of inductor alternators in order to produce ripples of increased frequency, which are filtered out from the fundamental frequency by the use of tuned circuits.

Various electro-static generators have been described by Bouthillion, Petersen, and Cabot.

Of the various alternators for high-frequency work the most successful has been that of Goldschmidt, which, if not extensively adopted, has been sufficiently developed to enable a transoceanic service to be maintained from Eilvese in Germany, to Tuckerton

in the United States, until the entrance of the latter country into the late war.

An example of this form of alternator was previous to the war to be seen at Slough, in England, and was still there until the end of 1916 when the author, whilst in military service, left this station.

This station was of small output (9 kw.) and designed to work with the much larger stations at Eilvese and a station near Brussels, the large aerials of which were a familiar sight from the Belgian State Railway, between Brussels and Liège. This station was destroyed before the entrance of the Germans into Brussels.

Since the action of the Goldschmidt machine is somewhat difficult to understand, it will be advantageous to first consider a method proposed by Cohen for the production of high-frequency energy, but apparently never adopted practice.

In this method instead of using, as is usual, direct current to excite the field coils of an alternator A_{2n} (Fig. 188), alternating current from an alternator A_n is used.

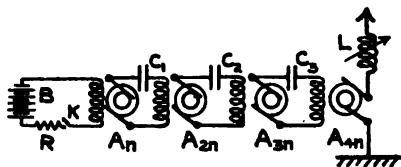


FIG. 188.—Cohen's high-frequency generator.

Since the exciting field of A_n will vary with respect to time the induced current must also vary. Let the frequency of A_n be n , then the field produced in A_{2n} will not be fixed in space but periodically reverses. The magnetic force due to such a rotating magnetic field can, by an elementary theorem of mechanics, be resolved into two component forces at right angles to each other, rotating with an angular velocity $\frac{2\pi}{T}$ in opposite directions.

One of these component forces will, with respect to the rotor windings (rotating with its own velocity $\frac{2\pi}{T}$), have no relative velocity and therefore induce no current, whilst the other component will have double the velocity, namely, $4\pi n$, and will induce current in the rotor of A_{2n} equal to $\frac{4\pi n}{2\pi} = 2n$, i.e. the

frequency of the current delivered from A_{2n} is doubled. The process can theoretically be repeated by the alternators A_{3n} , A_{4n} , etc., giving respective currents of frequency $3n$, $4n$, etc. Commencing with a moderately high original frequency of 20,000 for A_n , we obtain from five machines a frequency of 100,000 quite suitable for long range wireless telegraphy.

An analogy of such frequency adders is given by Goldsmith as follows:—

“Imagine a circular platform of moderate dimensions rotating once per minute, such as a roundabout used at fairs. Suppose further that the attendant walks back and forwards along a *diameter* of the rotating platform and he makes one to and fro trip in one minute, that is, the same length of time required for one complete rotation of the platform. His path as viewed from an external fixed point, such as the ground beneath the centre of the platform, can be inferred from Fig. 189. This shows a series of successive positions of the diametrical line along which he walks, each figure being 45° further advanced than the preceding (i.e. one-eighth of a revolution). This diameter is seen to have reversed its direction in the half revolution between positions 1 and 5. The position of the man on the diametrical line is indicated in each case by the dot. It will be seen the man never succeeds in getting to the right of the centre of the platform because, as positions 3 and 7 are reached, he comes to the reversed end of the diameter.

“The important point is that the path of the man relative to the ground (i.e. the curve ABCDE) is a closed curve, and that he has returned to his original position in a *half revolution* of the platform. In other words, relative to the ground, he moves in a closed curve at twice the speed, or double the frequency the platform rotates.”

This illustration should serve to show that an oscillatory movement of frequency n , taking place on a system rotating with frequency n , is equivalent relative to a fixed external point, to an oscillation of half the amplitude or width of swing and *double* the frequency.

If this principle is once thoroughly grasped the mode of increased frequency in Cohen's series of alternators is at once seen. Goldschmidt's alternator may be regarded as a series of Cohen machines of which the windings are all wound upon a single rotor and stator.

The action may be appreciated from Fig. 190 in which a motor serves to drive a directly coupled generator rotor, produc-

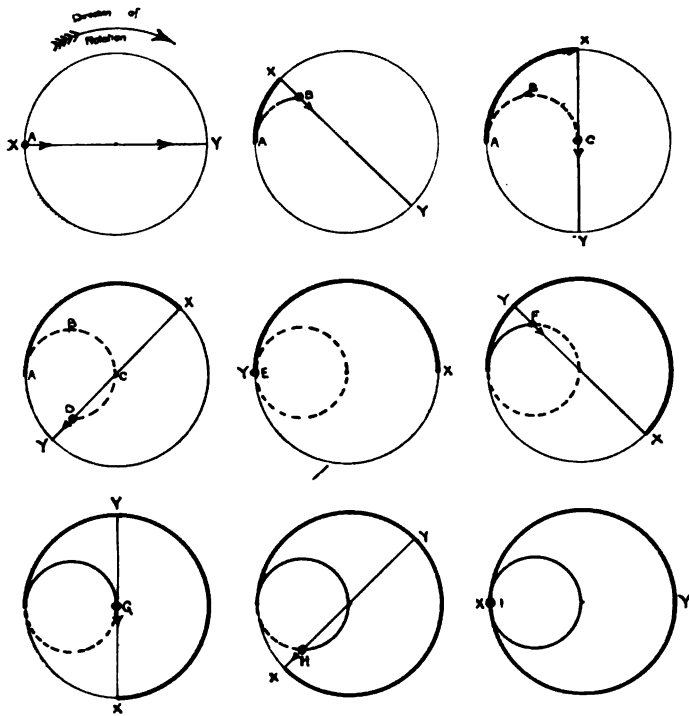


FIG. 189.—Principle of Goldschmidt frequency machine.

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ing alternately current of a relatively low frequency of 10,000 cycles, which is supplied to a circuit formed by the rotor windings and an external condenser C tuned to 10,000 cycles.

The 10,000 cycle current in this circuit, by its passage through the rotor windings, induces an e.m.f. in the stator windings, which, as we have already seen, will have an increased frequency of $2n$, i.e. 20,000 cycles per second. In order to utilise the $2n$ current induced in the stator field windings, a tuned external circuit D is shunted across the stator terminals, so that all the oscillatory energy passes into this circuit rather

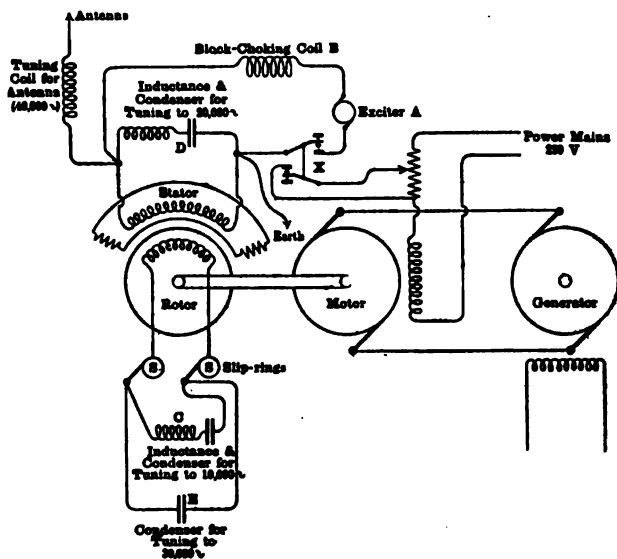


FIG. 190.—Circuits of Goldschmidt's high-frequency machine.

than through the non-oscillatory field coil circuit, passage into the latter being prevented by the insertion of suitable choke coils B in the field circuit, which permits the exciting direct current to pass whilst preventing the oscillatory currents from being forced into this circuit.

The current of $2n$, flowing in the stator windings and the circuit first tuned, again induces upon the rotor windings, giving a frequency of $3n$ (30,000 cycles) which is tuned out from the 10,000 cycle circuit C, by the insertion of a condenser E to tune to 30,000 cycles, the energy of this frequency taking the tuned path E, rather than the mistuned path C. The process

is again repeated in the stator windings and the resulting energy of 4π (40,000 cycles) may then be used to excite a long wavelength aerial, going to earth as indicated. In practice it is more usual to utilise a fundamental frequency of 20,000 so that four steps give a frequency of 80,000 cycles and a wavelength of under 4000 metres.

For signalling the machine is operated by the key X in the exciting circuit which besides exciting the alternator and so supplying power to the aerial circuit, controls the speed of the motor, in order to obtain steady rotation and therefore pure sine wave generation. As seen from the diagram, the field of the generator is separately excited, and runs at a constant pre-determined speed. The field of the driving motor is also supplied from the mains and contains a resistance which can be cut in or out as the switch X is opened or closed, i.e. when energy is being supplied to the aerial. The effect of this is that the motor tends to speed up a sufficient amount to counteract the tendency of the generator speed to drop owing to the increased output. The result is that the speed remains constant at 3100 revolutions per minute.

In operation it is found that by well tuning each circuit *in order* energy is immediately drawn from the circuit of immediately lower frequency. The higher circuit collects all the energy, since the energy of the lower circuit which before tuning occurs is being evolved as heat by resistance, inductive and dielectric losses now finds, by its use for excitation, an outlet into the higher frequency circuit.

The construction of the Goldschmidt machines is far from simple, since both rotor and stator have to carry high-frequency windings. The former is the most difficult circuit to build and must be so highly laminated that the iron laminations are as thin as the cigarette (rice) paper with which they are interleaved, to prevent eddy currents.

The production of such thin laminations of large size requires specially constructed machinery for their stamping and for the removal of the burrs on the edges after stamping. The rotor, being very largely paper, is also very non-rigid for rotation at the fairly high speeds necessary for the fundamental frequency. In this respect the Alexanderson machine is to be preferred, being of the solid inductor type with no rotating windings.

The use of the Goldschmidt alternator up to the present must be regarded as largely experimental, in spite of the long range

service maintained by 250 kw. machines during the late war. The high cost of manufacture is unlikely to make their adoption very general.

FREQUENCY CHANGERS.

The frequency adders, of which the Goldschmidt machine is the best-known example, suffer, as compared to the frequency changers about to be described (of which the Arco machine of the Telefunken Company is the best-known example), from the following disadvantages :—

1. To change from any given fundamental frequency to the required frequency, a greater number of steps are required. For example to change from 20,000 to 80,000 cycles, four steps are required by the Goldschmidt machine, but only two steps by the Arco machine. This difference becomes very much greater with still further increase of frequency. Since each step introduces high inductive and dielectric losses, a much greater overall efficiency is obtained by frequency doublers.

2. Frequency doublers can be supplied for their fundamental frequency by inductor machines. Since the transformations of frequency occurs in non-moving or static transformers, these can be as highly laminated as desired without any danger, such as occurs by loss of rigidity, with highly laminated rotating windings. The doublers can also be oil-cooled. Both these effects greatly increase the efficiency.

Together the two effects give a very much greater efficiency for frequency doublers as compared to frequency adders.

Frequency doublers may be themselves divided into two classes :—

1. Those dependent upon rectifying valves.
2. Those dependent upon magnetic phenomena.

We have already frequently referred to the rectification produced by crystal contacts as used in receiving apparatus.

Many other devices may be adopted for converting alternating current into unidirectional pulses. Amongst the best-known is the Lodge tube, where by suitable dimensions and shape of the electrodes in a discharge tube, this effect can be obtained. The thermionic valve can also be used in this manner, and O. O. Kruh has also adapted the mercury arc to this purpose.

Amongst the most practical rectifiers are certain electrolytic cells, such as aluminium electrodes in sodium molybdate solution, or an aluminium and a lead electrode in ammonium molybdate solution.

Whatever the type of rectifier used, if we apply an alternating source of current, assuming the valve passes current for the first half cycle, this current will grow to a maximum, and then fall off as the alternating source reverses. During the reversed half cycle no current will be passed.

A valve, inserted to pass current in the reverse direction, would not permit any passage during the first half cycle, then on reversal of the source, the current would first grow and then fall off.

We may illustrate the effect by Fig. 191, which shows the

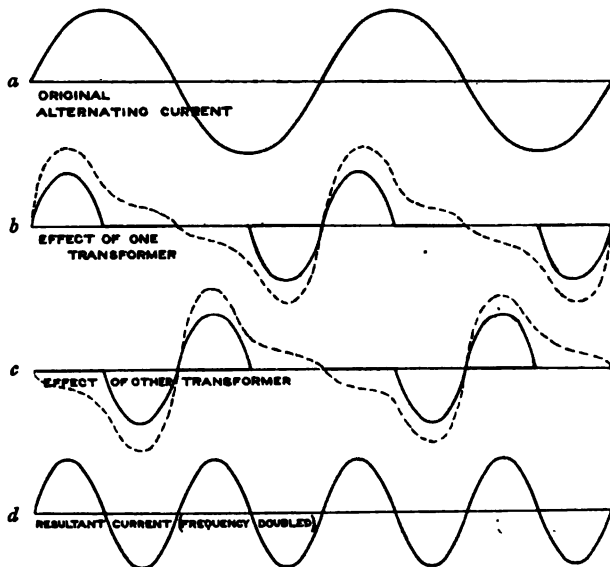


FIG. 191.—Principle of frequency doubler.

magnetic doubler. In the whole-line curves *a* would represent the current variations of the original alternating source, *b* the effect of the valve only passing current during the first half cycle, *c* the effect of the valve only passing current during the last half cycle. It is easily seen that if we could combine the effect of both valves in a single circuit, we should have an alternating current *d*, of double frequency as compared to the original source.

Suitable connections for this purpose are shown in Fig. 192 A. This requires four valves, but Zenneck has modified the arrangement, in order to reduce the number of valves to two, by use of two transformers (192 B) which may be combined into an

auto-transformer (as in 192 C). In all forms energy is passed through a coupling into an oscillatory circuit such as an aerial.

The use of such valves for frequency doubling (largely due to the work of Zenneck) has, since the inception of magnetic

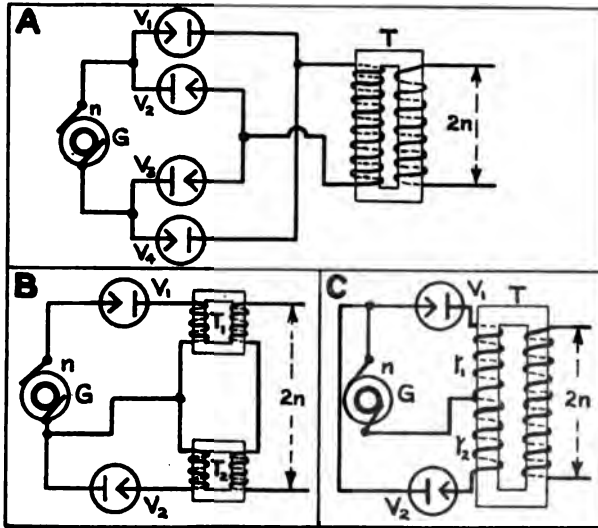


FIG. 192.—Connections of valve doublers.

doublers, been neglected. The method would appear to be capable of practical application, and possibly offers advantages over the magnetic type.

The action of the magnetic doubler is very much the same as the foregoing. If we take the ordinary B' - H' curve of any magnetic material, such as soft iron in a permanent field H , it is easily seen that at a point B (Fig. 193) equal changes α in the magnetising force will, since the iron is already practically saturated, if it assists the field H , produce only a small rise γ in the induction B , whilst if the change opposes the field H , it will produce a very great decrease β in the induction.

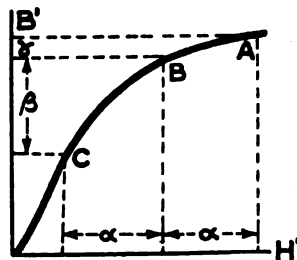


FIG. 193.— B/H curve for iron.

If, therefore, our additional magnetisation is due to an alternating source of current, and the field H to a direct current source, during one half cycle of the alternation, energy will be

transmitted through a secondary transformer winding, and during the other half cycle the energy will become wattless and no current be transmitted.

By the use of two transformers (Fig. 194) having primary windings, 2, from the alternating source, 1, a direct current source, 4, to provide the steady magnetic field by the windings, 5, wound in a reverse direction on each transformer, it is easily seen that if during the first half cycle the transformer permits a pulse of current as in Fig. 191 *b*, then owing to the reversal of

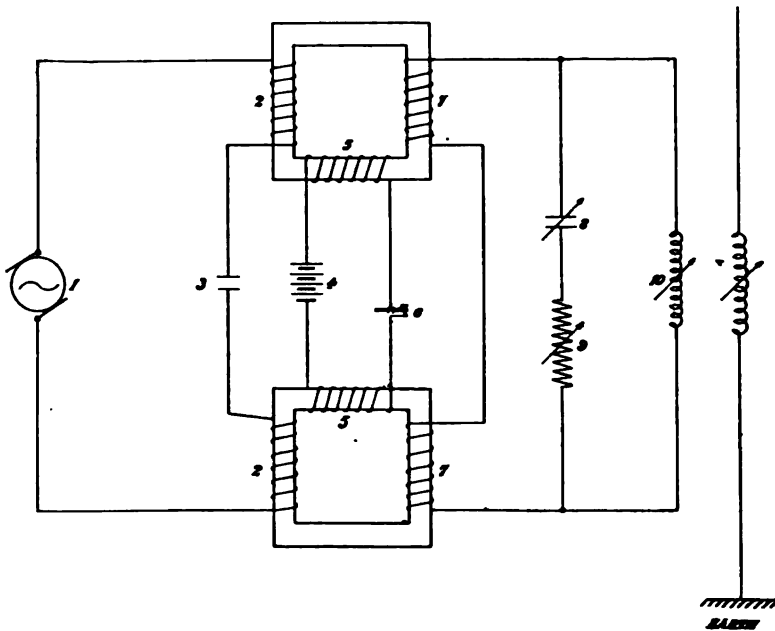


FIG. 194.—The magnetic doubler.

the field winding in the lower transformer during the last half cycle, pulses of current will be transmitted as in Fig. 191 *c*.

Hence a common secondary winding, 7, to the two transformers will receive an alternating current of double frequency as in Fig. 191 *d*, particularly if the secondary circuit is tuned to the double frequency, by insertion of suitable capacity, 8, and inductance, 9.

In practice the curves *b* and *c* shown in Fig. 191 will not be of the pure sine form shown by the whole lines but will be more correctly shown by the dotted lines. The secondary current, *d*, due to their sum, will, however, have a pure sine form.

Such a frequency doubler can be used for wireless telegraphy or telephony if a transmitting key or relay, 6 (Fig. 194), or a microphone, is inserted in the direct-current circuit, and transfer of energy from the secondary windings occurs to a suitable aerial from the coupling, 10.

During signalling the Morse key is depressed and one wavelength (of frequency $2n$) is radiated from the aerial. On releasing the key, and so removing the steady magnetic field, direct transformation will occur between the alternating windings, 2 and 7. If the useful double frequency gives a wavelength of, say, 10,000 metres, the frequency of n will give a wavelength of 20,000 metres which for efficient radiation, is above the usual present-day capabilities of aerials. Since, therefore, traffic by other stations does not occur, on such a long wavelength the emission of this spacing radiation does not greatly matter.

For lower wavelengths, say 5000 m , the emission of the spacing radiation of 10,000 m would be objectionable to other stations. To prevent this the aerial is thrown automatically upon a suitable dummy aerial of high resistance to destroy this non-useful radiation.

In connection with these useful and "spacing" radiations it is interesting to note that Round states that, with a fixed Artom direction-finder, the useful and spacing radiations from a fixed transmitting station may show a directional difference as great as 30° .

This type of magnetic frequency doubler has been largely adopted by the Telefunken Company, and is known by them as the Arco high-frequency machine. Two such machines of over 400 kw. output are installed at the Nauen station, and since they can be utilised in parallel with an aerial output of over 800 kw., there is little doubt that the Nauen station is the station having the longest range in the World. Enormous ranges have been obtained by the installation, signals from which can be easily received in Australia, and even farther away, so that the radiations are propagated in any direction half round the world, i.e. an exactly opposite station in the opposite hemisphere might be considered as receiving energy from both directions, and could possibly so carry out important observations on wireless propagation. Nauen is also heard at the Telefunken Funibashi station in Japan, i.e. right across Europe and Asia, all overland.

A similar but smaller station of 100 kw. was installed in 1914 at Sayville, near New York. Other stations of 400 kw. have been installed to maintain communication between Holland

and the Dutch East Indies, and one is in course of erection at Ovresøeter in Norway for Transatlantic work.

A comparison of the growth of the Nauen station in ten years is given by the following table:—

	1908.	1912.	1918.
		Small Aerial. Damped Waves.	Large Aerial. Undamped Waves.
Mast	One of 100 metres	Two of 150 metres One of 135 metres	Two of 260 metres Four of 120 metres
Surface area of aerial	31,000 sq. metres	77,500 sq. metres	155,500 sq. metres
Primary energy . .	50 kw.	175 kw.	600 kw.
Aerial energy . . .	12 kw.	100 kw.	400 kw.
Overall efficiency .	24 per cent.	60 per cent.	66½ per cent.
Range	3600 km.	8000 km.	20,000 km.

The installation of 1908 is the ordinary open-spark transmitter, that of 1912, the Quenched-Spark installation, already described in Chapter X., and the 1918 installation is of the high-frequency machine type. The 1912 installation is also retained at the present station and has a separate aerial system. Arrangements are present for duplex working by both stations simultaneously.

The current from the high-frequency generator is doubled twice to 24,000 cycles, and then excites an aerial whose wavelength is 12,500 metres.

A telegraphic speed of 200 words per minute is stated to be obtained with this enormous output, to control which the aerial variometers are so great that they have to be varied by a motor drive.

Whilst the practical application of such machines was due to Graf von Arco of the Telefunken Company, and the practical details were largely worked out by Kuhn and Meissner, such a method cannot in principle be claimed as purely a Telefunken method.

It was first proposed by Einstein in 1902, and was developed by Joly (1911), Spinelli (1912), and also Vallauri, the latter combining both transformers into a single three-leg transformer, such as used for 3-phase work, and reducing the number of windings from six to five.

For the theoretical considerations in the design of such alternators and transformers, the papers by Osnos in the "Jahrbuch der drahtlose Telegraphie" should be referred to.





FIG. 195.—Wireless telephony installation on board the "Waterland,"
1914.

[To face p. 395.]

The Telefunken Company in 1914 were the first to install a high-frequency machine on board a vessel for direct continuous wave generation, all other forms of alternator up to this date

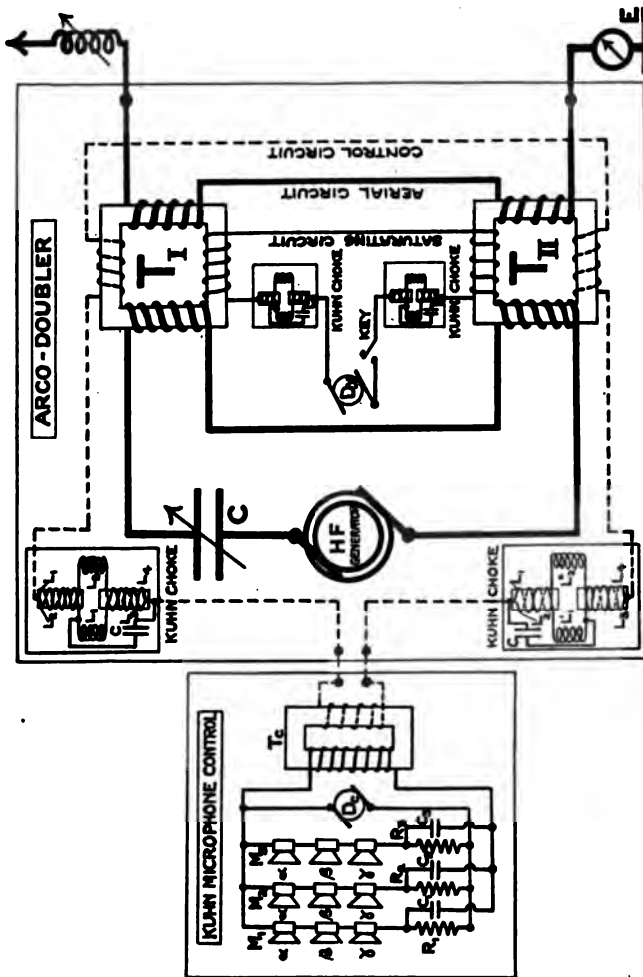


FIG. 196.—Arrangement of Telefunken continuous wave generator for telegraphy or telephony.

being too complicated. This set was installed upon the "Vaterland" in 1914, but owing to the outbreak of war has done little actual work.

An illustration of the installation is given in Fig. 195, and the actual scheme of connections in Fig. 196, which also shows

the telephonic control, the set being capable of being utilised for both telegraphy and telephony. For telephony the Kuhn control method was utilised, consideration of which is postponed.

For telegraphy this set utilised in 1914 a musical tone producer for producing at the transmitting a regular series of interrupted continuous wave trains of audible frequency, a method which has since become known in England as I.C.W. (interrupted continuous wave), and also under the more fanciful name of "Tonic Train".

This installation could be run from a 110 volt supply, from the ship's mains or from an emergency battery, driving a motor actuating a directly coupled 10 kw. 10,000 cycle alternator, an example of which is shown in Fig. 197, installed at Messrs. Siemens' Woolwich Works in 1912 for experimental purposes.

The frequency is raised by four transformations to 160,000 cycles, corresponding to a wavelength of 1880 metres.

In the middle of the top panel in Fig. 195 may be seen the helium tube control already dealt with in Chapter V. This with continuous waves shows a uniform circular band of light. If a musical sound affects the microphone transmitter, the circular band becomes broken into narrow radial bands, the relative brightness of the centres of the bands and the darkness of the middle of the space between them indicating very roughly the completeness of modulation.

The top row of instruments comprises the voltmeter and ammeter for the direct-current supply to a special small motor, the direct-current ammeter for the permanent magnetising circuit, the ammeter for the telegraphic relay for the 80,000 cycle transmission, and a 0-40 aerial ammeter for transmission, at this periodicity on a wavelength of roughly 4000 metres.

The second row of instruments are the large motor ammeter of the "magnetising" circuit, an 80 ampere ammeter for the 10,000 cycle output circuit, a 10 ampere instrument for indicating the current from the microphone transformer T_c of Fig. 196, and an aerial ammeter for telephony.

The lower panel carries the main switch of the motor generator set, the switch for the magnetising field, and the control switches, fuses for the helium tube and ventilating fan motor.

The centre lower panel carries the transmitting relay, a field resistance, the regulator to vary the musical tone producer for interrupted continuous wave telegraphy, and the handwheels controlling the variometers of the 10,000, 40,000, and 80,000 cycle telegraphy circuits. On the right lower panel are the



FIG. 197.—Experimental high-frequency generator at Siemens' Works, Woolwich (1912).

[To face p. 396.]



variometer handwheels for the 20,000, 80,000, and 160,000 cycle aerial circuits, the frequency meter for indicating the frequency of the interrupted continuous wave pulses, and a battery of 8 to 10 microphones for telephony.

On the desk is the sending key, which acts via the relay already mentioned, and on the bottom panel to its left are the motor starters and regulators.

The installation is controlled both for telephony and telegraphy by a single operator who need not move from his seat. All the apparatus, such as variometer coils, is situated behind the panel, whilst the motor generator is installed at a distance.

For telegraphy upon 1900 metres wavelength, the aerial current is 6 kw. and less for telephony. According to Dr. Kuhn a microphone output of 4 watts, corresponding to a control alternating current of 8 amperes through the 30 turns of the 40 microhenry control windings of the final transformers, serves to control several kilowatts of aerial energy, the amplification being 1000.

Such an installation permitted, in 1911, on a 5000 metre wavelength, wireless telephony to be carried on between Nauen and Vienna, over a distance of 340 miles, and this range was extended in 1913 to Pola, over 550 miles. In spite of heavy atmospherics the speech was good, vowels being, however, emphasised, and consonants sometimes missing. Singing was faultlessly transmitted.

Figures given by the Telefunken Company about 1912, for the output of such installations, but which have doubtless been since much improved upon by specialised research on the construction of the necessary iron core high-frequency transformers, are as follows, for a machine of 15 kw. output driven by a 25 kw. motor:—

Periodicity.	Wavelength (Metres).	Aerial Energy (kw.).	Number of Transformations.	Efficiency.	
				Per Step.	Overall.
10,000	30,000	15	—	—	—
20,000	15,000	11	1	73	73
40,000	7,500	7.5	2	68.2	50
80,000	3,750	4.5	3	60	30
160,000	1,675	1.5	4	33.3	10

Guaranteed ranges were given for such an installation as 300 miles by day, 450 miles by night on the 3750 metre wavelength

when used for telegraphy, but only 30 to 40 miles when used for telephony.

Since, however, the Telefunken Company at this period considered the range with continuous waves, as compared to Quenched-Spark installations, as only two-thirds the latter, and later experience has shown continuous wave ranges to greatly exceed spark ranges, the above figures must be regarded as based upon purely experimental work about the date given.

The A. E. G. have patented a doubling arrangement shown in Fig. 198, in which the separate windings of the transformer may be regarded as direct coupled.

The application of the magnetic static high-frequency generator is not limited to single-phase work. On the contrary Spinelli, in 1911, suggested the use of the same principle for

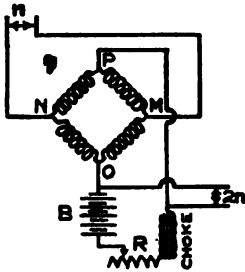


FIG. 198.—A. E. G. frequency doubler.

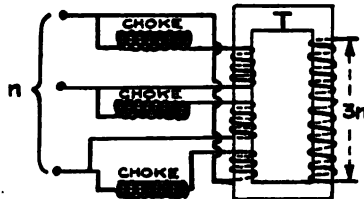


FIG. 199.—Taylor's tripler.

increasing the frequency, with a 3-phase supply, not for wireless purposes, but for lighting purposes.

A. M. Taylor has, since 1909, in England, been experimenting in this connection for wireless purposes, and his paper in the "Journal of the Institution of Electrical Engineers," 1914, is the only standard English paper on such frequency changers which, since with a 3-phase supply the frequency can be increased threefold, are perhaps better named changers or multipliers. Taylor's tripler has the great advantage of requiring no permanent magnetising field.

Taylor has described the construction of 3-phase transformers, giving for an output of 28 kw. an efficiency of 86 to 88 per cent., very high when one considers the small efficiencies of high-frequency work. For a 100 kw. transformer he expects an efficiency of 90 per cent. and for 500 kw. 95 per cent.

He has successfully constructed a transformer for 9-phase

work, giving a ninefold increase of frequency, so that with an inductor alternator of relatively low frequency of 11,000, a frequency of 99,000, quite suitable for wireless purposes, can be obtained. He also proposes a 27-fold transformer which with a generator of quite low frequency of 3666 cycles would give 99,000 cycles.

His methods of connection for 3-phase frequency multiplication are shown in Fig. 199.

Doubtless future work will see the further introduction of such magnetic multiphase frequency changers into actual wireless practice. Since the low-power magnetising circuit makes them more easy to control than the arc-transmitter, they offer undoubted advantages over them for wireless purposes.

One other method of frequency doubling due to Zenneck must be briefly mentioned.

One of the great disadvantages of Poulsen arc-transmitters are their great unsteadiness of frequency. This is due to the production of harmonics of the fundamental oscillation.

Zenneck has proposed the use of such arcs with an alternating current supply, with which the third harmonic of the supply frequency is most pronounced, and to filter out and utilise this harmonic by means of a tuned circuit.

In connection with the nomenclature of these high-frequency machines of various types, to overcome the cumbersome nature of the digits it has been proposed to call 1000 periods per second "The Hertz," from which we have the relation

$$\text{wavelength} = \frac{\text{Number of Hertz}}{300}.$$

VALVE-TRANSMITTERS.

Whilst Fleming introduced the 2-electrode thermionic valve into wireless practice, and De Forest introduced the far more useful 3-electrode valve, neither of these investigators appear originally to have had the slightest idea that it could be used as an intensifying device for reception, or, as an actual generator of continuous waves.

The amplifying property was first utilised by Lieben and Reiss, and then greatly improved by Meissner of the Telefunken Company by adoption of high vacua or hard tubes, a result also obtained independently by Langmuir in the United States.

To Meissner must also be paid the credit of realising in 1913 the possibility of using the 3-electrode thermionic valve for

transmission, a result in which he was closely followed by Armstrong in the United States in the course of a few months. Since this period the valve has been generally adopted for the generation of continuous waves.

A word of warning must, however, be given to the enthusiastic regarding valve generators. Whilst the American G.E.C. have manufactured Langmuir's plotron tubes for outputs of several kilowatts, the valve is by no means developed for very large outputs. The Telefunken Company state (1919) that their largest output from a single tube is 4 to 5 kw., the limit being reached by the manufacturing possibilities of the glass container. A 10 kw. valve-transmitter is installed at Nauen.

The possibilities of long-range transmission by valves is therefore limited, at least for the present. Undoubtedly in the future long-range continuous wave work will be carried on by the use of frequency changers, such as the Arco machine, shorter ranges up to 1000 miles by spark-transmitters, whilst small range telegraphy and telephony, such as from ship to ship, by valve generators.

Whilst the valve offers a very convenient method of generating oscillations of any desired wavelength, their cost and comparatively short life and high cost of running, as compared to spark-transmitters, at present limit their extensive use for commercial telegraphy.

It is true the output can be increased by the use of many valves in parallel, for example in the 1915 telephony experiments between America and France, De Forest states that many hundreds (570) of parallel valves were used. Such transmission, whilst marking a distinct advance, must be regarded as purely experimental and impracticable as a commercial proposition.

Perhaps the most notable patent in regard to valve manufacture for higher powers is that of De Forest in 1917 (Brit. Pat. 100,959), which in place of glass utilises a metal container sealed by mercury. Whether this valve has given practical results has not been stated as far as the author is aware.

The action of the valve as a generator has been dealt with mathematically by various physicists, the most notable being Vallauri, Bethenod, and Latour to whose papers references are given.

Such papers are interesting, but to the average non-mathematical person engaged in wireless technology, they convey little information. Since mathematics are of use in so far as they are a means to an end for the elucidation of physical problems, and

should not be used in order to render a problem more involved to the uninitiated, the author does not follow many precedents, and forbears their reproduction.

The action of the valve as an oscillator can be appreciated as follows:—

We have already seen (Chapter VII.) that in a valve used as an amplifier, small voltage variations impressed upon the grid (v circuit of Fig. 69) will cause the production of greatly magnified variations in the plate circuit (V circuit of Fig. 69), the energy for the latter being drawn from the high-tension supply.

Let us suppose that, instead of the grid variations being due

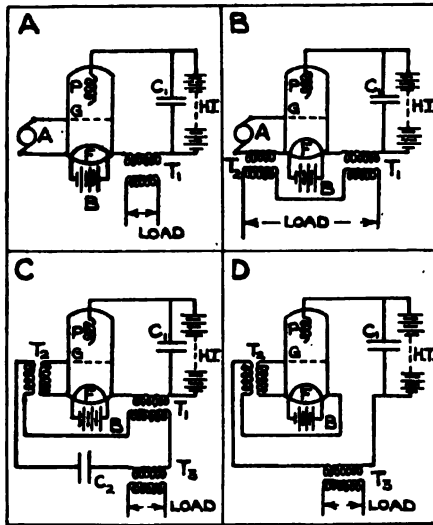


FIG. 200.—Action of the thermionic valve as a generator.

to received aerial oscillations as in the reception case, they are due to the insertion of a small alternator A, supplying a simple harmonic current Fig. 200 A.

In the plate circuit similar current variations will occur if the high-tension battery is shunted by a suitable condenser C_1 . We have therefore a direct conversion of direct-current electrical energy of the battery into alternating-current energy, and it is a simple matter to draw this energy off, for any desired purposes, such as for wireless radiation, by means of a suitable transformer T_1 .

Suppose also, instead of utilising all this plate circuit energy, we lead a small portion of it back to the grid circuit by means

of a second transformer T_2 (Fig. 200 B). Assuming there is no difference of phase between the alternations of the alternator A and the plate circuit oscillations, the energy entering the grid circuit via T_2 will assist that of the alternator. So the energy exciting the plate circuit will be increased, and consequent stronger alternations will occur in the plate circuit, until the limit is reached at which the emission of electrons from the valve filament is insufficient to pass more energy through the valve, or the dimensions of grid and anode electrodes cannot carry more energy without undue overheating, or the plate circuit battery is unable to supply sufficient energy.

Further, our plate circuit being, by the insertion of suitable capacity and inductance, such that it has a natural oscillatory period given roughly by $t = 2\pi\sqrt{LC}$, the application of potential from the high-tension battery across the condenser C will tend to cause to set it into oscillation. However small such oscillations may be, by their passage through the transformer T_2 , they will excite the grid circuit and so tend to build up stronger oscillations. We thus see that by suitable adjustment of our circuits we can entirely dispense with the hypothetical alternator A which we have only inserted to render our explanation more clear, and we shall then have circuits such as Fig. 200 C, in which the plate and grid circuits are coupled together by an intermediate circuit tuned by the capacity C_2 .

Such a method of using the valve for actual generation of high-frequency currents was first utilised by Meissner and forms the subject of German Patent No. 291,604 of 9th April, 1913, and corresponding to British Patent No. 252 of 5th January, 1914.

This method of self-excitation of the valve Meissner originally termed "backcoupling" (Rückwirkung). It has since become more generally known as "retroaction". The use of retroaction is not entirely due to Meissner since it is first mentioned in an Austrian patent of 11th December, 1912, by Strauss, who collaborated with Lieben and Reiss. Strauss, however, merely applied such retroaction for intensification of received signals and apparently did not consider the valve as being capable of use for generation.

It is a simple step to replace the transformer T_1 of Fig. 200 C by a direct, instead of a magnetic coupling, as in Fig. 200 D. Such a method, known to Meissner when his original patent was applied for, nevertheless forms the basis of a separate patent for improvements by Round of the Marconi Company, No. 13,248, dated 29th December, 1914. Since to an engineer it is

an obvious step in filing a patent specification to word it to include all known methods of coupling circuits together, and since Meissner states that he collaborated with Franklin and Round after his original discovery, it would appear that by virtue of the Telefunken-Marconi Agreement each commercial company applied for patents to place them upon an equal footing in regard to valve generation. Certainly the use of the thermionic valve employing retroaction to generate oscillations is first protected by Meissner, so that the later Round patent would seem merely to protect the use of suitable alternative circuits for a like purpose.

Armstrong, by a U.S.A. patent of July, 1914, also protects the use of retroaction for valve generators. According to Meissner this patent was filed after knowledge of his own discovery.

The patent situation, which is therefore somewhat uncertain, can be entirely overcome by the use of a separate oscillating valve to replace the alternator A of Fig. 200 A. Since this does not involve retroaction in any way, and since De Forest allowed his 1906 patent covering three-electrode valves to lapse, the manufacture of three-electrode valves is generally open to anyone. There appears to be no legitimate patent to prohibit the free use of valves for generating oscillations suitable for wireless telegraphy and telephony, so that valve transmission is by no means the monopoly of any one commercial wireless company.

By means of such a retroaction set, Meissner in March, 1913, was able to carry out telephonic transmission between Berlin and Nauen. He used the unmodified Lieben valve which is the most prominent feature of the installation and with a plate voltage of 440 obtained an output of 12 watts, an aerial current of 1.3 amperes on a wavelength of 600 metres.

Later he obtained telephonic transmission between Berlin and London, speech being received by Round at Marconi House by, the author believes, a Lieben valve.

Shortly after Round evolved a similar installation for the Marconi Company, using his modified form of valve.

Whilst Meissner's experiments of 1913 were significant, they were not at this period commercially practicable since, owing to the ionic bombardment of the filament in the soft Lieben valve, the valve life was as short as 10 minutes.

Meissner appears to have soon recognised the necessity for using a hard valve to avoid such disintegration of the filament.

This does not appear to have been recognised by Round,

since in 1915 the Round valve was still a "soft" valve, and remained so in the British Army until superseded by the hard "French" valve, due to Latour. Langmuir in the U.S.A. also produced his hard "Pliotron" during 1914 and 1915 which overcame the defect of the original soft valve.

Since this date the patents taken out for methods of design of valves both for reception and transmission and for circuits for their use are legion. It will add little to our knowledge to consider the various arrangements which are purely for the valve specialist. Nor does it add greatly to our knowledge to include characteristic curves of the large number of valves evolved.

We have in Chapter XI. already described the small continuous wave transmitter used as a trench set in the British Army. The longer 120 watt C.W. wagon set of the British Army, having a range of 250 miles, has also been considered. Similarly, installations in the British Army are now increased to 500 watts and have the long range of 800 miles.

During the late war our Navy employed valve transmitters for transmission up to 1600 miles, and the Portsmouth Signal School propose to design multiple valve sets to deliver 120 kw. to the aerial, fused silica replacing the glass containers.

In Chapter XII. we have described the small R.A.F. continuous wave transmitters for telegraphy and telephony of which the greatest feature is their extreme simplicity of operation.

Since this book specifically deals with the Telefunken and Quenched-Spark systems, it will not be out of place to describe a small 10 watt installation which has been extensively manufactured by the Telefunken Company for ship installations, submarines, and, according to Nieman, was largely adopted upon the German aeroplanes.

This installation is illustrated in Fig. 201 *a* and its connections given in Fig. 201 *b*. It is designed with a view to simplicity of operation, and is intended for telegraphy either with continuous waves or interrupted continuous waves.

In order to make it independent of the ship's lighting supply it is worked from a special high-tension direct-current generator, which is itself driven from a suitable battery of 14 volts. It is noticeable that the high-tension supply in this respect follows the original example of the Lieben valve which used such a source of high tension. On the adoption of the valve in England the general tendency was to use batteries for this purpose. Since such batteries have a very small capacity they



FIG. 201 a.—Telefunken 10 watt C.W. aeroplane or ship set.
[To face p. 404.]



will not give a great current and their use is therefore exceedingly expensive. To overcome this the British Army adopted "H T. units" which were essentially induction coils giving unidirectional pulses of current. These units were not very satisfactory, and later high-tension generators were utilised, so following the original German practice.

To render the current output steady the generator is shunted by a large capacity which serves the purpose of storing up energy, so that variation at the brushes of the generator is minimised, since the energy delivered is first stored upon the condenser plates, and by the large capacity the voltage is not greatly affected by changes at the brushes.

This motor-generator and its battery form a separate unit of the installation. The apparatus case shown contains the valve transmitter, the valve receiver, and a four-valve amplifier

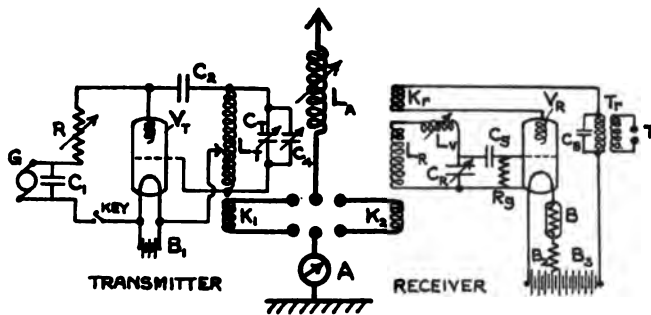


FIG. 201 b.—Scheme of connections of Telefunken 10 watt valve set.

which can be used if necessary. The machine is direct coupled and delivers 0.1 ampere at 650 volts.

The interrupter for producing the I.C.W. radiation is a separate unit and rapidly interrupts the grid circuit of the transmitting valve. The type of valve used is that illustrated in Fig. 72 (4) for transmission and in Fig. 72 a (3) for reception.

The generator feeds the valve plate circuit across the condenser C_1 already mentioned. To prevent passage of direct current into the oscillatory plate circuit the valve C_2 is inserted, whilst to prevent passage of oscillatory current into the generator windings a suitable choke coil is used.

Retroaction between grid and plate circuits is obtained by variation of the relative coupling of a direct coupled inductance L_T in both plate circuit. Such a direct coupling allows a strong reaction to be obtained, as is desired, whilst any

flatness of tuning is eliminated from the aerial circuit by imposing the intermediate circuit formed by the same inductance L_T and variable condenser C_T . This condenser allows this circuit to be tuned from 380 to 780 metres wavelength. A shunt condenser C_s serves to vary the tuning during calling up, in order to aid the opposite station to more easily detect its signals, which with sharply tuned continuous wave transmitters is more difficult than with flatly tuned spark-transmitters.

Transfer of energy occurs from this intermediate circuit by means of the coupling K_1 which is switched into the aerial circuit during sending. The aerial as usual comprises a suitable high-frequency ammeter A and a variable inductance L_A .

The receiver is nearly a replica of these circuits. Energy is transferred from the aerial by the coupling K_2 (put in circuit by a change-over aerial switch) to an intermediate circuit formed by inductance L_R and variable condenser C_R and sharply tuned by the inductance. Retroaction between this circuit and the valve plate circuit occurs by the magnetic coupling K_r , the variometer L_R also serving to adjust this retroaction of the two circuits. The grid circuit is fed across the variable condenser coupling C_R , which also serves to regulate the energy transfer. This circuit contains the usual grid condenser leak C_g , the use of which in reception has already been dealt with (Chapter VII.), and a high resistance R_g is inserted as a leak.

The filament circuit is fed from a battery common to plate and filament circuits. This circuit is noticeable by having, in addition to the adjustable resistance a barretter of iron wire B . Since with rise of temperature the resistance of iron increases, this serves as an automatic control to regulate small increases in filament current, so maintaining a steady filament electron emission.

The plate circuit, retroacting as already mentioned, is coupled to the telephones or receiver by the transformer T , shunted by a blocking condenser C_B .

Its high-tension supply is from 35 dry cells giving about 50 volts.

The telephone can be directly coupled to the plate circuit for strong signals or by means of a switch, the signals can be intensified by inserting a four-valve amplifier, which is really a separate unit but built into the common case.

The connections of this intensifier are shown in Fig. 202. It has four valves fed by a common filament circuit controlled by resistances R_1 and R_2 .

The incoming signals from the receiver are transferred through special iron core transformers T_1 - T_3 , from the terminals 1 and 2, from valve to valve, the last two valves being in parallel.

Fig. 201 *a* shows the actual instrument. In the top left-hand corner is the aerial variometer, and in the top right-hand corner the receiver variometer. Between these variometers is the handle of the condenser of the calling device already mentioned, below the "send and receive" change-over switch, and the telephone plug sockets.

The opened flap shows to the left the four valves for the receiver intensifier, and to the right, two transmitting valves.

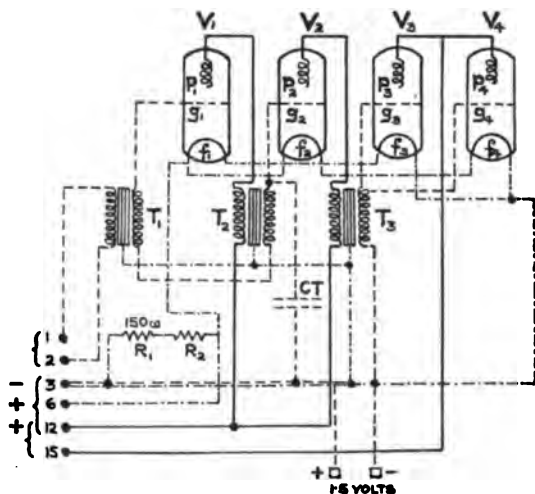


FIG. 202.—Telefunken four-valve amplifier.

Calibration curves to adjust the wavelengths for sending and receiving are inside the flap which has apertures, so that the valves can be seen when it is closed.

Aerial and earth connections are seen upon the sides of the case. Signalling occurs by interrupting the generator circuit by Morse key.

Larger installations than this are manufactured, but they are all based on the same general scheme.

Increase in power is obtained by use of larger valves and their connection in parallel. At Nauen a valve transmitter is used utilising eight large valves in parallel, and radiating about 10 k.w.

The entrance of the United States into the late war, and the existing state of war between Germany and the United States has prevented any great extension of the Telefunken valve generators since having already lost her colonies, America was the only foreign country with which German wireless stations could work.

To increase the size of valve stations is merely a question of utilising more valves in order to increase output, irrespective of their cost and possible commercial application.

In this respect the Arlington-Eiffel Tower experiments have already been mentioned, and over a shorter range of Ireland to Canada the Marconi Company in 1919 conducted Transatlantic telephony with an aerial supported by 500 feet masts, an aerial current of 16 amperes, and a wavelength of 12,000 metres.

THE MODULATION OF AERIAL ENERGY FOR TELEPHONIC PURPOSES.

For wireless telegraphy the problem of signalling is simple, since in order to control the emission of energy from the aerial it is only necessary to insert a Morse key either directly or indirectly, by means of a relay, in some suitable low-tension circuit.

When we come to the problem of telephony, however, the problem is by no means so simple. It is now not only necessary to control the energy during intervals of speech, but also necessary to vary the aerial energy emission according to the frequency and varying intensity of the human voice.

Up to the present we have advanced no legitimate reason for the necessity of using continuous waves for wireless telephony.

The human ear can possibly distinguish the air waves constituting sound over an extreme range of frequency from 20 per second to 10,000 per second, although the average range is much more limited than this. The sound waves actually produced by the human vocal mechanism are much more limited in range, and normal conversation is conducted with a frequency having a mean value of about 800 per second.

Since the aerial must emit at least one wave, controlled (i.e. modulated) in accordance with each sound wave, we shall require the emission from the aerial of at least 800 waves. Furthermore, since speech is continuous, this emission must be similarly continuous with respect to time. As we have seen, to produce such a continuous radiation we must utilise either a

pure continuous wave generator, or the simulation produced by very rapid sparks with their consequent defects.

The wavelength necessary for such a voice frequency is easily obtained from the relation $n\lambda = v = 3 \times 10^8$ metres per second, from which for n equals 800, λ equals 375,200 metres, or 230 miles.

The enormous aerial which would be necessary for such a wavelength may be realised when it is stated the largest stations, such as Nauen, use a wavelength not greater than 20,000 metres, i.e. only about one-twentieth of the required wavelength. The cost of construction of even such aerials is so enormous that only a few nations possess even one station of this size, and still fewer more than one. Hence, wireless telephony cannot be generally used by such means.

Whilst instead of this long aerial system we could increase the wavelength by artificial loading, this immediately reduces

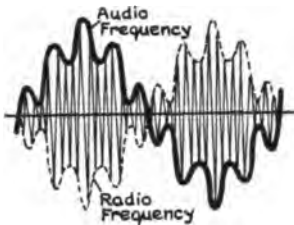


FIG. 203.

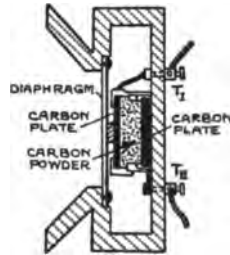


FIG. 204.—Microphone arrangement.

the efficiency, and would do so to such an extent, that Goldsmith calculates that, with an ordinary aerial of 100 metres length at 800 cycles, an aerial current of no less than 3000 amperes and a voltage of 1,000,000 would be necessary to radiate 1 kw. Such a method is clearly impracticable.

The alternative method is therefore to allow one sound wave to modulate a number of electro-magnetic waves after the manner illustrated in Fig. 203, where, in order to render the diagram of reasonable size, the thin line electro-magnetic waves are not drawn in a true sine form, and are also shown greatly diminished in number, according to the real ratio of electro-magnetic to sound waves, which it is simple to calculate for a wavelength of say 600 metres, namely 625.

This section will deal with the actual methods of converting the air waves of the voice into electrical waves in order to modulate the wireless transmitter. The problem of reconversion of

electrical waves of inaudible frequency to a frequency which can be appreciated by the ear is best deferred to the next section.

The conversion of the energy of air waves, constituting human speech, into electrical energy for wireless radiation, is obtained by means of some form of microphone. Of the very many forms of microphone which have been adopted, the most common is the carbon granule type.

Essentially the carbon microphone consists of an electrical circuit completed through loosely packed carbon granules (Fig. 204). With a constant source of external electromotive force applied via terminals T_1 , T_2 , the resistance will vary according as to whether separate carbon granules make good or bad contact, and hence the current in the circuit will similarly vary. If the granules are packed closely together a larger number of parallel paths through the carbon will exist, and the total resistance is therefore less than is the case when the granules are loosely packed, and fewer parallel paths exist.

If we imagine a piston, by its movement, to alternately compress and decompress the granules, the resistance and current through the circuit will vary with the movements of the piston.

If this piston is made of some light material capable of being set into movement by the impact of air waves, due to the action of the human physiological vocal mechanism upon the air, the current in the circuit will vary with the human voice.

To obtain such a modulation of the electrical energy our piston is formed by a suitable diaphragm. This diaphragm must consist of some material of sufficiently light weight to rapidly respond to air waves, and, therefore, having little mechanical inertia. Furthermore, the diaphragm must be aperiodic, that is, its own natural period of mechanical oscillation must differ greatly from the general periodicity of the voice air-waves, in order that it will not, by resonance, be itself set into vibratory movements.

Various materials can be used for this purpose, such as metals, but the best practical material would appear to be a sheet of mica.

As soon as we apply such a microphone to modulate an electrical circuit, which in turn is intended to modulate the output of the wireless transmitter, difficulties arise. If the current passed through the microphone is very great, the small sparks which occur between adjacent granules, not only cause the addition of a great deal of hissing noise to the transmitted voice, but also cause the microphone to become heated and lose its power of

varying the local circuit in accordance with the diaphragm movements.

We might attack this difficulty by only using a small microphone current, and before application for the control of energy output relaying this current external to the microphone. Until quite recent years the only type of practical relay was the magnetic type, and as soon as we commence to relay a weak current, distortion occurs owing to the mechanical and electrical inertia of such relays. The problem so becomes exceedingly difficult and nearly impracticable. The introduction and perfection of the thermionic relay has done much to render this aspect of the matter relatively easy of solution. As the current which a microphone can modify is small, our only recourse is to use a number of such microphones all equally modified by the same spoken sound, and each contributing its separate effect to a common electrical circuit by connection in series, parallel or some other form of connection. Here again we meet with difficulty. As it is impossible to make the microphone resistances absolutely equal, small local currents occur between microphone and microphone, and these destroy the exact variation of the current with human speech sounds.

This difficulty can only be overcome by keeping the number of microphones as low as possible, and by their accurate manufacture in order to reduce great differences of resistance. Such a small number soon becoming heated when in use, we have to adopt some method of cooling as by an external air current, and arrange for their rapid replacement by a similar series as soon as they become heated. This replacement can be rapidly made by a switch, and during non-use the previously used and heated microphones are able to cool to their original temperature. The objection to such a method is that it soon becomes cumbersome in practice, but in the early days of wireless telephony it was the only method available.

Types of Microphones.—Previous to the introduction of the thermionic valve in order to magnify electrical currents without the introduction of inertia effects, very many investigators introduced special types of microphones capable of dealing with much heavier currents than is possible with the simple carbon granule microphone. The thermionic valve bids fair to supersede all such microphones, many of which, whilst giving good results in the hands of their inventors, are too complicated for ordinary commercial use.

Amongst the most notable attempts in this direction are those of—

1. Marsi, who overcame the heat production by causing a stream of carbon to flow between the microphone electrodes, and so to constantly renew the carbon granules.

2. Dubilier, who arranged two diaphragms to give a double effect upon the same volume of carbon granules which were also water-cooled.

3. Marsi, who entirely replaced the carbon granules by a stream of liquid electrolyte. The flow of this stream, and therefore its electrical resistance, was modified by a needle valve, the needle of which was actuated by the microphone diaphragm. Such a method was only possible by use of alternating current, since otherwise the electrolyte became rapidly polarised and incapable of electrical modification.

4. Jervis-Smith used a similar method, in which the diaphragm modified not the rate of electrolyte flow, but the length of the stream and therefore its resistance.

5. Vanni, who, in 1912, had very considerable success in wireless telephony up to ranges of 600 miles, used a normal carbon microphone to actuate a sensitive electro-magnetic relay. This actuated a lever, having an inclined plane, the vibration of the latter, in its turn, modifying the flow of an electrolyte.

6. Chambers utilised a liquid microphone in which the thickness of a film of liquid, constantly flowing from a jet, was modified by the movement of a diaphragm in close opposition to the jet. The resistance between jet and diaphragm was varied to a degree corresponding to the diaphragm movement.

7. Majorana, who, in 1908, had success in wireless telephony up to ranges of 180 miles, utilised a microphone controlling the drop formation of a fine stream of an electrolyte, caused to impinge upon two electrodes.

8. Sykes used a flow method, in which not only the length or cross-section of the electrolyte was caused to vary, but the concentration of the salt in the electrolyte, by arranging a microphone to control the mixture of an electrolyte with a non-electrolyte.

Of the various forms of manometric flame microphones which have been proposed space does not allow us to deal.

It is noticeable that since the introduction of the thermionic valve to magnify the sounds delivered from a carbon microphone, without defects due to inertia, new methods of magnification by means of magnetic relays have been introduced and used in practice.

These magnetic relays have received a new name of "ferro-

magnetic control," and one is due to Alexanderson of the American G.E.C. and one to Kuhn of the Telefunken Company, the latter company having extensively used the Kuhn relay in practice.

The action of the Kuhn relay may be inferred from Fig. 205, where the heavily drawn circuits are oscillatory circuits, the first having an high-frequency generator of the Arco type, and the second being a closed circuit, or a tuned aerial circuit.

Transfer of energy from the former to the latter occurs via an iron-core transformer, and efficient transfer depends on the two circuits being sharply resonant to each other.

If upon this transformer we wind a third winding (shown light) which includes in its circuit a microphone *M* and battery *B*, it is easily seen that variations in the microphone resistance will vary the current in this circuit and hence by means of this third winding vary the permeability of the transformer iron. Unless the two oscillatory circuits have an exactly equal number of windings the value of the inductance of each circuit will vary differently. They will so be thrown out of resonance with each other, and transfer of energy from alternator to aerial circuit will be very greatly diminished.

Hence variations of the microphone in the aperiodic circuit will very effectively control the heavy current oscillatory circuit transfer, particularly so, since the saturating windings of the Arco generator keep the permeability of the transformer iron at a critical value in the actual arrangement, shown in Fig. 196.

Transfer of energy from the oscillatory generator circuit will naturally be small since the microphone circuit is aperiodic, i.e. non-oscillatory, and is further prevented by the insertion of choke coils. This allows quite a small current through the microphone to control a very heavy aerial current.

For good results the damping of the oscillatory circuits must be small, in order to permit, with a suitable degree of coupling, this circuit to be sharply resonant to the alternator circuit. It should be particularly noted that this relay differs from the magnetic relays of the type described in Chapter VII. in so far that whilst these relays depend purely upon changes of permeability of the transformer cores, in the Kuhn relay the relay action depends essentially upon changes in resonance.

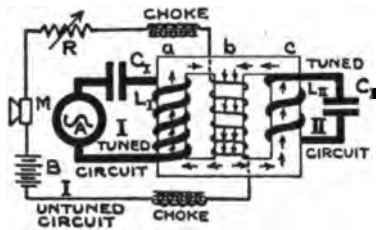


FIG. 205.—Principle of the Kuhn relay.

This method has been extended to permit the microphone circuit to modify not only the alternator circuit but at the same time to modify the inductance of the aerial, so throwing this in or out of resonance and giving a greater degree of control.

This system of control, as used in practice, has been illustrated in Fig. 196. A number of microphones are inserted in series-parallel and in each series bank is a large resistance shunted by a condenser, the whole arrangement being fed from a direct-current generator of constant output. When the resistance of the microphones decreases, the current increase tends to pass through the condenser, so keeping the current through the resistance practically constant.

For these controls the transformers have to be of special design to reduce iron and copper losses to a minimum. They are usually a 10 to 1 step-down transformer which actuates the

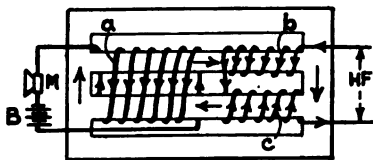


FIG. 206.—Principle of Alexanderson relay.

permanent saturating currents of the Arco high-frequency system transformers.

The Kuhn choke system for prevention of back surges of energy into the microphones should be particularly noticed. These do not take the form of normal choke coils, but, as may

be seen two iron chokes, each with a double winding shunted by a capacity. This method prevents back surges in two ways. Firstly, the whole choke is, by means of its condenser, tuned to the frequency of the back surges. This results in its offering nearly an infinite impedance to the surges, so choking back current. Secondly, the double reversed winding on each cone causes incoming energy surges to split up equally in the windings, but the fields established in the iron cores tend to neutralise each other, and so to prevent energy flow.

The Alexanderson magnetic control is quite distinct from the foregoing. This depends upon changes of current in the microphone circuit, causing a rapid change in the saturation of the iron cores, and so varying the inductance of the high-frequency circuits. The whole feature of this method is that the high-frequency windings are by the method of winding shown in Fig. 206 caused to neutralise each other's flux. Hence, back surges of energy from the high-frequency circuits, if the windings are similar, balance out their effects upon the microphone circuit. In order to lower the impedance, the high-frequency windings may be in

parallel to each other, each shunt path having a condenser inserted in it.

This method has been used to directly control the energy of a 75 kw. Alexanderson high-frequency generator with good results.

The same principle as the Alexanderson magnetic control has been applied to thermionic microphone controls by the American G.E.C. in their British Patent 21,388/1914, by the use of a thermionic valve having a single filament but symmetrical double grid and plate electrodes.

The high-frequency generator is directly in the aerial (Fig. 207). Back surges of energy from the aerial into the microphone circuits are limited by the potential produced on the grids, and reversed current from plate to filament cannot therefore pass into the microphone circuit shunted across the filament and grids.

These patents illustrate the use of double grid and plate anode valves, originally due to Schottky.

Such valves also have the advantage that energy can be modulated by them during both half cycles of the transmitter, so giving an increased effective radiation, as compared to microphone and valve arrangements where only one half cycle is used, when the grid has a positive potential. This advantage can otherwise be also obtained by the use of thermionic valves in parallel, but reversely connected as in Zenneck's frequency doubler.

Causes of Speech Distortion.—In addition to the practical difficulties experienced in producing a microphone capable of carrying the comparatively heavy power to control a wireless transmitter, we have to overcome defects of the microphone itself, which produce a distortion of the speech.

This problem has up to the present received very little attention, and that only since the surmounting of difficulties in the production of continuous waves, which now renders telephony comparatively easy. Hence the whole subject is still in an embryonic state and incomplete.

One defect can best be studied by "characteristic" curves in which sound wave energy is plotted against the microphone's electrical energy.

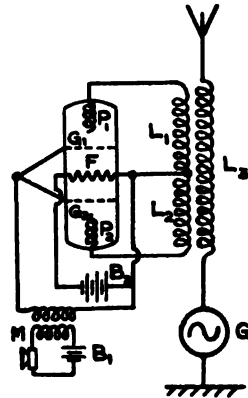


FIG. 207.—Protective method of valve control.

For the ideal case this would be a straight line passing through the origin as in Fig. 208 I., where the sound wave and electrical waves if plotted together upon suitable scales would absolutely coincide and give a single line as shown to the right.

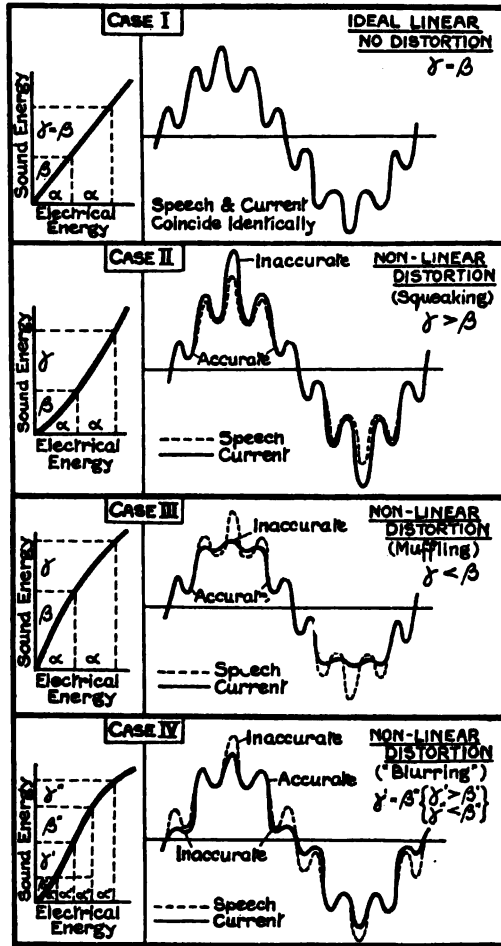


FIG. 208.—Types of speech distortion.

In actual practice, however, the characteristic is not linear, but takes the form of either Fig. 208 II. or Fig. 208 III., or a combination of both the foregoing as in Fig. 208 IV. Since the

characteristic is not a straight line, this is known as non-linear distortion.

Fig. 208 II. shows the case in which the response to a value of sound energy β gives a value a , but where a sound having an energy value $\beta + \gamma$ where $\gamma > \beta$, only gives a value $2a$, so that the energy ultimately radiated is greater for large sound energies than for small. This leads to a distortion of the electrical radiations, and hence to the received sound, which can be appreciated from the right-hand curve, where it is seen that low energy tones of the voice cause a less radiation than the higher tones.

Similarly with a characteristic, as Fig. 208 III., the effect is reversed, high-sound energy tones being more weakly radiated than low tones.

With the combined effects the distortion is shown by Fig. 208 IV., where whilst for mean energy sound values the energy evolved is accurate, for high and low extremes distortion occurs.

The practical effects for the first type of non-linear radiation is that the speech is "squeaky," due to exaggeration of high notes, in the second speech is "drummy," due to exaggeration of the lower notes, and in the combined form the speech is "blurred".

Further distortions may be produced, such as the characteristic not passing through the origin but crossing the y axis, so that very weak sounds cause little or no radiation, whilst strong sounds do so.

A source of trouble investigated by De Forest is due to the passage of infinitesimal sparks or arcs between adjacent carbon granules. These on subsequent amplification cause a hissing noise.

The introduction of the thermionic valve has largely rendered the use of electro-magnetic relays unnecessary, but with these as in line telegraphy the effect of the inductance is to cause a lag in the establishment of current. This lag being greatest for weak sounds, causes the accentuation of strong sounds at the expense of the weak, a defect which can be partly corrected by the introduction of capacity.

Whilst such defects are especially present in electro-magnetic relays using iron cores such as described in the first portion of Chapter VII., they are still present in thermionic relays, since a small but appreciable time is still necessary to establish the magnetic fields of the inductances (without iron cores) used to tune the circuits. Such fields are established much more quickly for strong sounds, and therefore strong microphone currents, than for weak sounds. Moreover, since higher as compared to lower

frequencies do not act upon the inductance for such a long period, the former may in extreme cases not have a sufficient length of time to establish the fields, and so they fail to be radiated. This defect, as mentioned in Chapter XII., may be largely overcome by a steady current which keeps the field established, so that the differences between strong and weak sounds tend to disappear, i.e. we permanently shift the x axis of our characteristic up so that the curve now passes through the origin.

The Application of the Microphone.—In Chapter XII. we have already dealt with the application of the microphone to valve transmitters, and seen that this may be inserted directly across a capacity or inductance in the aerial circuit, or in the plate or grid circuits of the valve.

The direct insertion of the microphone in the aerial circuit, as used in the early days of wireless telephony, suffers from the defect that emission is continuous, and modulated by a change of aerial resistance, and therefore tuning of the energy generating circuit and aerial circuit. The aerial is thrown in or out of tune more or less in accordance with the variations of sound energy, and the energy transfer from one circuit to the other so modified.

Since this continuous radiation varies over a wide wavelength range, it leads to great interference with other stations, and will doubtless be soon prohibited by law, as the open or Marconi aerial was prohibited for telegraphy.

The present-day method as used in the Air Force telephony transmitters is to apply the previously magnified microphone energy across a condenser in the aerial circuit. Round, however, claims certain advantages for the grid method of control whilst regretting that this was so obvious that it did not become the subject of a patent.

The control of the plate circuit, since this requires the control of a comparatively heavy-current circuit by a low-current microphone circuit is not capable of such ready utilisation.

When we come to the other forms of continuous wave generators we can place microphone batteries in practically any circuit, either directly, by a coupling, or via an intermediate circuit.

It is obvious, however, that the best results will be obtained in a low-tension circuit, such as the "saturating" windings of a frequency doubler or by a separate winding acting in opposition to the saturating winding, as in the Kuhn control.

With all forms of control, the objection is that a long wave range is necessary for telephony. For telegraphy only one wavelength is required, and the non-useful radiation can, in telegraphy, be rendered unobjectionable to other stations by the

automatic insertion of resistance in the aerial, in order to dissipate the non-useful energy between the signals. This method is still possible with telephony transmitters when not actually radiating speech, and is not necessary in the "quiescent" aerial valve method, where the valve only oscillates during actual speech.

For the direct insertion of the microphone in the aerial, Eccles has, on theoretical grounds, advocated a microphone resistance equal to half the sum of the radiation and ohmic resistances of the aerial.

In all coupled microphones it is advantageous in practice to earth one terminal of the microphone to remove changes in capacity between speaker and microphone, and also to guard the speaker against shock.

With arc-transmitters the microphone may be inserted via a suitable resistance in parallel to the arc. This parallel circuit will by its variation also vary current through the shunted arc, so tending to vary its high-frequency generation by changes in arc resistance, and causing more or less aerial radiation.

THE RECEPTION OF CONTINUOUS WAVES FOR TELEPHONY AND TELEGRAPHY.

When for either continuous wave telegraphy or telephony we have overcome the problems of generation of high-frequency currents and the difficulties of microphone control, we are faced with the fact that upon reception at a distant station the frequency will be so great, that it is above the frequency range audible to the human ear.

With the spark signals used in telegraphy the telephone diaphragm responds at the beginning and end of each spark train and the summated effect of the regular series of clicks is to produce a musical note, audible to human ear, throughout the period of reception.

With rapid oscillations the only effect is for the received currents to build up and cause a click at the beginning of reception, then, because of its mechanical inertia, the telephone diaphragm refuses to respond and remains in one position until the end of reception, then falling back.

There are two main methods of overcoming this non-response of the telephone diaphragm.

1. To rapidly interrupt the received currents by intervals of time which are sufficiently long to permit the telephone diaphragm to respond effectively to the undamped wave train received during the intervals of non-interruption.

Thus in Fig. 209 the upper curve *a* shows the continuous

oscillatory train received in the aerial circuit, the centre curve *b* shows the response in the receiver closed circuit, which after an interval of $\frac{2}{3000}$ of a second is interrupted for $\frac{1}{3000}$ of a second. The lower curve *c* shows the building up of the charge upon the blocking condenser of the telephone and its subsequent discharge. It is seen that in unit time the frequency of blocking condenser discharges are much less than the wireless frequency, but vary in accordance with the modulation of the wireless energy over the period of time during which the closed circuit is uninterrupted, so that separate condenser discharges

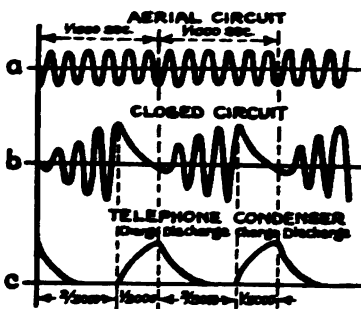


FIG. 209.

will vary in energy in accordance with the received aerial energy.

The interrupter is known technically as a "tickker".

2. This method depends upon "beat" reception, a well-known phenomenon in the physics of sound, where, each time two oscillatory systems of slightly different frequency come accurately in phase, a large mutual transfer of energy

occurs, since the separate oscillations do not mutually interfere.

This method of beat reception has received the more fanciful term of "heterodyne" from America, which, it is to be regretted, has not only been adopted in England but still further elaborated by such terms as "ultra-heterodyne," "auto-heterodyne," "mono-heterodyne," etc., which, whilst serving to make the technology more difficult to the novice unlearned in dead languages, do not add any further information to those aware of the physical phenomena of beats.

To produce these beats special mechanical apparatus, such as the Goldschmidt Tone Wheel, may be used, but of recent years a much simpler method has been available in the form of an oscillating valve.

The Tickker.—This may merely consist of a suitable form of buzzer with a high rate of vibration of its armature.

The use of such a buzzer has been dealt with in the Tone Converter of Chapter VI., where, instead of being used to chop up continuous wave signals, it was used to chop up slow spark unmusical signals, in order to render them musical as with rapid spark signals.

The use for continuous wave reception is essentially the same, except that previous use of a detector is unnecessary, the tickker replacing this.

Poulsen introduced a very sensitive form of tickker consisting of two very fine gold wires, one of which made contact to the axle and the other to the periphery of a small rapidly rotating wheel.

The vibration of the gold wire upon the periphery of the wheel either alternately opened or closed the telephone circuit, or modified the energy of this circuit by variations of the resistance of the contact.

The practical difficulties of such an instrument was to overcome that of maintaining the gold wire in a state of constant and equal vibration, a difficulty later surmounted by having the wire brush fixed and acting against teeth and interspaces upon the rotating disc.

Goldschmidt's Tone Wheel.—This was devised by Goldschmidt to overcome the disadvantages of tickker reception when using his high-frequency alternator.

It is really a modified form of tickker in which the rotating disc is rotated at a critical speed. To ensure regularity of action the gold wire is replaced by a small copper gauze brush and the interspaces of the rotating disc are filled with some insulating material to avoid frictional vibration of the brush.

Goldschmidt's improvements entailed the use of a motor to rotate the disc at a very constant speed, so that for incoming electrical oscillations one-half cycle could be caused to flow through a circuit completed through a metallic tooth of the Tone Wheel, whilst the other half cycle was prevented from flowing by the interposition of the insulation of the Tone Wheel slot.

The whole action was therefore that of a mechanical rectifier, but since these rectified pulses had the same periodicity as the aerial oscillations they were still inaudible except at the beginning and end of the radiation.

If, however, the disc is rotated at a slightly increased or diminished speed to that causing pure rectification the telephone will receive first a number of pulses in one direction followed by a number of pulses in the reversed direction, i.e. beats occur.

The summated effect of each series of pulses will cause the charging of the telephone blocking condenser, alternate charges being reversed in electrical direction. The condenser will, for each series, discharge through the telephone and, the frequency

of beats being much smaller than that of the original electrical oscillations, the result is an audible note, the pitch depending upon the relative frequencies of incoming signals and number of teeth passing the brush per second.

Since the latter can be varied by regulation of the driving motor, the pitch of the note can be varied to suit the ears of the receiving operator. This advantage, together with the advantage that signals from other continuous wave stations produce notes of widely different pitch, whilst spark signals do not produce any note at all, also serves to eliminate jamming, both advantages being common to all forms of beat reception whether mechanical or electrical.

The Tone Wheel may also be used as a wavemeter. By measuring the speed of the driving motor and knowing the number of teeth upon the disc, the frequency of interruptions are known. If this frequency is such that beats are just eliminated (the first case mentioned), then a series of half-cycle pulses in one direction are being received. The cycles are then equal in number to the teeth. The frequency of the former is so known and the wavelength can easily be determined.

It must be noted that with a two-fold increase of this speed, a complete cycle would be conducted by each tooth, and similar for a three-fold speed. Hence the correct wavelength will be as determined by the first production of silence after audible signals are heard.

Fessenden's Method.—This method, known as “heterodyning,” is true electrical beat reception. Near the receiving aerial (Fig. 210) is a wavemeter whose tuned circuit L_2C_2 is rapidly charged and discharged by a high-frequency buzzer G . This serves as a source for superimposing locally generated oscillations upon the oscillations actually received from a distance by the aerial. If the wavemeter frequency is slightly different from the aerial frequency, large pulses of current due to beats and capable of affecting the telephone in the detector circuit DBC_3 are produced. The pitch of these beats is within audible limits, and can be varied at will by adjustment of the wavemeter frequency.

In practice the aerial and wavemeter circuits are magnetically coupled by a double winding upon the magnet of the telephone as shown in Fig. 210.

Valve Reception.—From Fessenden's method it is a simple step to modern-day valve reception of continuous waves. We have seen that the valve not only can be used as an intensifier but also as a generator of oscillators.

If, therefore, we cause a valve to generate oscillators comparable in magnitude to the oscillations of incoming signals, but differing slightly in frequency, and if we couple the valves plate oscillating circuit to the aerial, electrical beats will be produced, the frequency of which can be adjusted to give any desired note, heard through a telephone coupled to the plate circuit.

It is immaterial whether we use the same valve which produces beats by its retroactive coupling to further rectify these beat oscillations, or whether we use a separate valve to do so. The former method is termed "auto-heterodyning," the latter "ultra-heterodyning".

Whilst one method reduces the number of valves and their adjustment, since to produce beats the valve circuit must be slightly mistuned to the aerial circuit, a decrease of energy transfer occurs. This may be remedied by a tighter retroactive coupling giving a greater energy transfer, but only obtained at the expense of selectivity. Jamming stations cannot then be so easily eliminated.

With the separate beat producing circuit, greater selectivity irrespective of retroacting coupling can be obtained. Also the local valve oscillator can, after calibration, be utilised as a wave-meter to accurately tune the aerial circuit. As a disadvantage a double set of valve circuit adjustments are required.

The modern use of "interrupted continuous waves" (Tonic Train) tends to displace all forms of special receiving apparatus at receiving stations for telegraphy. Since the radiations of one sending station may be received by a large number of receiving stations, from a broad point of view it is far more economical to install a single interrupter at the sending station, than to install special interrupting or beat-producing apparatus at a large number of receiving stations.

Furthermore, since heavy currents are being dealt with at the sending station, the interrupting mechanism can be much more robust, and therefore more reliable than an interrupter at the receiving stations, having to deal with only very minute received currents.

Also in the event of an urgent message as an S.O.S. signal, all other stations, whether spark or continuous wave, can then receive such signals without additional apparatus.

Advantages of Continuous Wave Transmitters over Spark Transmitters.—Whilst in general C.W. transmitters of all types

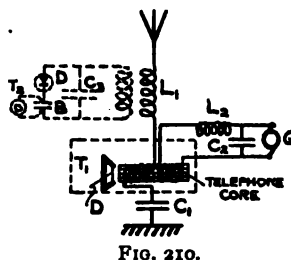


FIG. 210.

are more complicated and expensive than spark transmitters, they have the very great advantage that they permit of much sharper tuning and selectivity than spark sets.

In any spark transmitters and in arc generators, oscillations of varying wavelength are produced either owing to the production of two waves by coupled circuits or by the production of overtones.

Whilst such defects are greatly reduced with Quenched-Spark Gaps, the practice of slightly mistuning the circuits to aid quenching still produces the radiation of energy upon multiple wavelengths.

Upon reception it is possible by very sharp tuning to eliminate all slightly differing wavelengths of smaller energy value. As the received energy is so reduced before transfer to the detector circuit, sharp tuning is always carried out at the expense of strength of signals. In practice the difficulty can be largely overcome by a suitable choice, but if two very sharply tuned transmitters are sending upon the same wavelength, the only means of eliminating jamming is by the use of a different musical note, as first introduced by the Telefunken Company, a method which is not always applicable.

With continuous waves, if the transmitter is well designed practically only one wavelength is radiated.

The beat reception method very greatly aids the eliminating of jamming. If, for example, we have a sending station radiating on a wavelength of 600 metres, i.e. a frequency of 500,000 cycles per second, and the local generating circuit used for reception has a frequency of 499,000 cycles per second, the beats produced per second will be 1000.

Let another radiating station have owing to mistuning a slightly different wavelength of 610 metres, then its frequency will be 491,800 per second. Its effect, at the common receiving station, will be to produce beats of 7200 per second. The difference of frequency between 1000 and 7200 gives an extreme variation of received note, and the former station can be very easily distinguished.

Such a variation in tuning of 6.1 per cent. given, is extremely common with modern commercial stations. Even with a variation in wavelength of two transmitters, only amounting to 600 to 601 metres, the beat frequencies will be 1000 and 800 per second, i.e. very easily distinguishable.

Non-sustained spark transmitters and irregular atmospheric will be entirely unable to form beats, and will not give a musical

note on reception. This great sharpness of tuning and advantage of beat reception overcoming jamming largely explains how the ranges of continuous wave transmitters are much greater than equal power spark transmitters.

The advantages are so great, that now every ship of even small tonnage is by law compelled to carry a wireless installation, and jamming is becoming beyond manageable limits; regulations are in course of being framed to compel all private messages sent by passengers, and not necessary for navigation, to be sent by continuous wave transmitters. Large vessels, catering for passenger traffic, will have such continuous wave transmitters installed, in addition to spark transmitters for navigational purposes.

It should be particularly noted that such an advantage is not shared by interrupted continuous wave, where the note variation does not occur on reception. This is a disadvantage of I.C.W.

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CHAPTER XIV.

THE MAINTENANCE AND OPERATION OF WIRELESS APPARATUS.

A. MAINTENANCE.

THE PRIME MOVER AND GENERAL REMARKS.

THE wireless operator is not usually concerned with the maintenance and running of the prime mover of a wireless station.

On ships, this prime mover is a steam engine driving a direct-current generator, supplying energy for lighting and many other purposes, including the supply of the wireless installation. It is therefore placed in the engine-room under the care of the engine-room staff.

At land stations, the prime mover may be a steam, gas, or oil engine and is under the charge of the wireless personnel. It would obviously be much beyond the scope of this book to attempt to deal with any of these prime movers, and indeed the necessary knowledge can only be obtained by practical experience. When such plant comes within the care of the wireless personnel, a suitable operator is chosen as chief operator, or superintendent, on the score of experience gained other than as an operator only.

For this reason the operator at sea has, if he exercises a little tact, the possibility of gaining considerable practical engineering experience, which will stand him in good stead when he wishes to obtain the better posts of his profession.

The author, speaking from experience whilst visiting many ships' installations, and otherwise, has often found considerable friction existing between the engine-room staff and the wireless operators. This is very often found to be due to the attempt on the part of the young operator to give instructions to the engineers. This is naturally resented by men, whose experience has been gained after years of apprenticeship, and whose engineering knowledge is far more extensive than that required to operate a small wireless installation.

Such friction can usually be avoided, and then the operator

will generally find marine engineers to be only too ready to assist him when in difficulties to the utmost extent. If the operator will endeavour to establish friendly relations with the engine-room staff he can usually obtain very many advantages. For example, when he wishes to charge his batteries he will possibly be obliged by the engine-room generator being run throughout the whole period necessary for charging, instead of his having to charge at intervals. He will usually be able to obtain skilled assistance and the use of necessary tools, for any small repairs which may be necessary, etc.

By such means not only will he be able to run his installation better in the best interests of the operating company and the shipowners employing him, but he will himself gain knowledge and experience, which will be a great asset to himself in his later career.

THE LOW-TENSION CIRCUIT.

The Motor Generator.—The purely electrical side of this machine is unlikely to call for much attention on the part of the operator, since electrical technology has generally reached such a high standard, that all machinery before installation is subjected to the most rigorous tests. For example, the insulation is tested for three or four times the maximum pressure the machine is likely to experience, except by the grossest mishandling.

The greatest attention required by the motor generator is in regard to its frequent periodical cleaning. Otherwise, particularly at sea and in the Tropics, dirt will accumulate in its windings and attract moisture, the final result being the rotting of the insulation, and its subsequent breakdown.

At large power stations, for the purpose of removing dust and dirt, electrical vacuum cleaners are often used. The operator should if possible endeavour to follow this procedure by obtaining a hand bellows, with the aid of which he can remove dust, etc., without interfering with the machine in any way.

After years at sea, even the most carefully attended machine is liable to breakdown. In such a case, unless the operator has actual engineering experience, he should not in any way attempt to repair the damage himself, unless this is obviously superficial in its extent. The advice of the ship's chief engineer should be sought regarding any extensive repairs, who, if he has the facilities at his disposal, and the necessity is urgent from the point of view of the ship's safety, will doubtless undertake the repair. From the

point of view of the wireless companies, they much prefer such work to be undertaken by their own agents, who have greater practical experience of such repair work. It may be mentioned here that many ships' electricians have little, if any, experience of electrical machinery winding, so the operator should be quite certain, before entrusting his apparatus to the ship's electrician, that he is capable of performing the work. In this respect, the chief engineer is most likely to be able to give a decision.

Other than very infrequent repair work, the chief points regarding the motor generator are as follows :—

The bearings should be kept well cleaned and oiled. Should they become dirty they must be washed out by petroleum, until the oil flows out quite clear, and then they should be filled with pure mineral oil, which, as the machine rotates at a high speed, should be fairly thick. This should be poured into the bearings until it flows from the overflow outlets, and these must then be screwed up firmly, to prevent the oil spurting out during running.

It should be particularly noticed, that *to fill the bearings above the outflow is a disadvantage and not an advantage*, since the oil rings, which by their motion causes the uniform circulation of the hot and cold portions of oil in the bearings, will stick, so preventing a good circulation and causing a rise of temperature.

The temperature of the bearings should be about 35° C. and never rise above 50° C., i.e. a temperature easily borne by the hand.

After being first installed the bearings should be frequently cleaned to remove any particles of metal worn off the bearing shells, which will cause injurious scratching. Watch the amount of oil in the bearings so that it does not get too low and cause bad running. The importance of keeping friction down as far as possible can be best appreciated by mentioning that at a newly installed station, after a great deal of checking of connections, testing the machine's circuits, etc., and finding them right, the cause of non-running was found to be merely due to the absence of oil in the bearings of the previously installed machine, which had never been run, but in whose bearings oil was assumed to have been placed during erection some time previously.

On board ship the motor generator is best installed in the direction of the vessel's length. This will prevent any end play (i.e. sliding along bearings) due to the rolling of the ship. If end play still occurs a washer should be inserted to prevent it, since the relative motion of alternator, rotor, and stator will cause variations of output, besides wearing the bearings.

The brushes of the motor should be frequently inspected in order to keep them clean from adhering particles of copper, which will cause bad contact as well as scratching the commutator. If the machine is of the slip ring type the brushes, when newly installed, must be ground to fit evenly upon the commutator. This is done by placing a sheet of emery with *the rough surface outwards* and rotating the armature by hand, until the brushes are suitably worn down. The brushes are usually stamped N and S and should be inserted in the brush holders with these marks upwards. Occasionally see that the brush holder springs are keeping the brushes well pressed against the commutator.

The commutator should be very occasionally cleaned with the very finest emery and then rubbed over with waste, slightly moistened with oil or special commutator lubricant. Too much lubricant is to be avoided.

When, after very long use, the commutator becomes worn, no attempt must be made by the operator to true it up by hand. If for any reason the makers or skilled electrical engineers cannot undertake the work, as on a vessel "on station" abroad, the services of the skilled turners of the engine-room staff should be solicited, but only when returning cannot possibly be delayed. If possible the consent of the operating company should be obtained before undertaking such work. The whole machine should be carefully cleaned at least once per week. On no account should oil, dirt, or sea water be allowed to get upon the windings or the insulation will break down.

If the alternator is not directly coupled to the motor (usual on ship stations), the belt drive must be kept neither too slack nor too taut. On direct-coupled machines, as on board ship, the coupling should be occasionally inspected to ensure it does not work loose. In the very rare cases of a geared motor and alternator, lubricant, as graphite, should be applied to the gearing.

The Starter and Speed Regulator.—As confusion, often exists in the minds of some operators as to the actual purpose of these parts of the installation the author will briefly digress into pure electrical engineering in order to explain them.

The fundamental phenomena upon which all electrical motors and generators depends, is based upon the fact that if a conductor is placed in a magnetic field and a current is caused to pass in it, a mechanical force is experienced by the conductor which tends to set it in the direction of the magnetic field, i.e. it tends to move and is a motor. Conversely, if a conductor is set

in mechanical motion in a magnetic field a current flows in the conductor, i.e. it is an electrical generator.

The actual forces concerned are in both cases directly proportional to the current strength, length of conductor, and the strength of the magnetic field in question.

In order to obtain as great a length of conductor as possible these are wound lengthwise upon a soft iron laminated coil, the whole arrangement being known as an *armature*, which is placed in an intense magnetic field produced by electro-magnets. Passage of current in the armature and in the magnets, or *field coils* causes, according to its relative direction, an attraction or repulsion between the conductors of the armature and field coils. The result is, the armature only being free to move, this is set into rotation. Electrical energy is so converted into mechanical energy in a motor and vice versa in a generator. To cause a flow of electricity in the rotating armature the mechanical commutator and brushes are necessary.

All motors fall into one of three types:—

(a) *Series motors*, in which the current supplied to the motor passes through armature and field coils in series. This type of motor is ill adapted to wireless work, since whilst capable of rapid starting, and rapid variation in speed, its speed varies greatly when, as in wireless plant, the load is intermittent.

(b) *Shunt-wound motors*.—In this type the field and armature circuits are in parallel. This arrangement permits of a rapid change of load with a small variation of speed, so that with a fluctuating load, it gives little variation in speed and is particularly adapted for wireless work.

(c) *Compounded motors*, which, by use of two sets of field coils, are both series and shunt-wound. They partake of the advantages of both the previous types.

In the best type of motor manufacture the armature and field coil windings are always brought separately to terminals on the machine, so that it can, if desired, be used as a series machine, or a shunt machine, according to the way these terminals are connected by means of copper straps (see Fig. 42, motor 6, A, B, C, D).

In practice the shunt-winding is used, with the smaller Quenched-Spark installations, and compounded machines for motors above 5 kw.

When an armature rotates between the poles of the magnet an electro-motive force or pressure is produced between the upper and lower brushes, which is found to be opposite to the

direction to which the current is flowing and will tend to stop the current. It is due to the armature by virtue of its motion, also acting as a generator and tends to oppose inflowing current.

The faster the armature rotates the greater will be the counter e.m.f., and the speed of the armature will be limited to that in which the counter e.m.f. has nearly reached the value of the e.m.f. applied to the brushes, leaving sufficient difference to overcome the resistances, both mechanical and electrical. In a well-designed motor these are small so that the counter e.m.f. nearly equals the applied e.m.f., and a steady speed of rotation is reached.

When a load is put on the motor the effect is naturally to reduce the speed, which itself reduces the counter e.m.f., the opposition to the applied current is diminished, and more current flows through it. As the force exerted on the armature windings increases with the current, the motor exerts a greater power, enabling it to deal with the increased load. When the load is removed there is an excess of power, which is employed in increasing the speed, so raising the counter e.m.f. and cutting off the excess of current. The action of the counter e.m.f. is, therefore, like the governor of a steam engine letting more current through when the speed drops and cutting it off when the speed rises. The counter e.m.f. also increases when the magnetic force is increased, so by strengthening the field the machine is caused to run more slowly, whilst by weakening it the speed is increased since the current is not cut off until a higher speed is attained. Hence, a convenient method of regulating the speed of a motor is by placing *a variable resistance in the field coil circuit, which, when increased, will weaken the current and cause increased speed, and vice versa.* Such a variable resistance is known as a *speed regulator.*

It is seen from the above that when the speed of a motor is below the normal an excessive current will flow through the armature. When starting a motor the counter e.m.f. is nil, since no rotation is occurring and an enormous current will therefore flow through the machine. This would, by breaking down its insulation, damage the motor. It is therefore necessary to put some extra resistance in circuit during starting in order to keep the current down to reasonable limits. As the speed increases this can be reduced, until it is eliminated altogether.

It is undesirable to reduce the current in the field coils since this reduces the consequent magnetic field and the maximum tractive force is not exerted upon the armature to cause rota-

tion. Hence the starting resistance is inserted in the armature circuit.

Resistances for this purpose are known as *starters*. They are generally designed so that the switch automatically returns to the off position when the current is cut off and so the motor cannot, unless this is deliberately done, be put directly upon the mains, but only via the starting resistance. A wire (Fig. 211) is taken from the shunt field circuit to a small electro-magnet m_1 upon the switch. This magnet, when the motor is

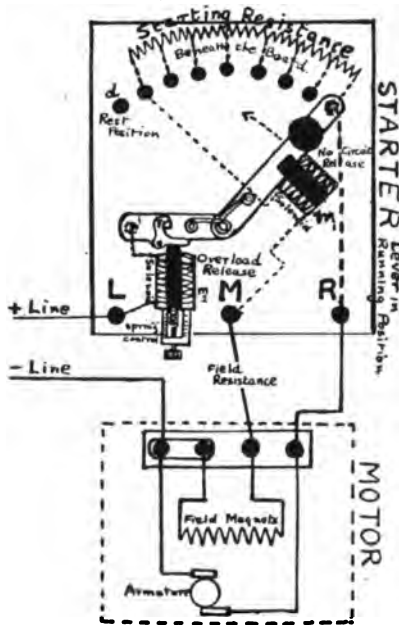


FIG. 211.—Connections of simple starter.

running and the switch is over to the right, attracts the switch and holds it in position with all the resistance cut out of the armature circuit. Directly the current is cut off, the electro-magnetic is de-energised, the switch flies back (to the left), and the starting resistance is put into the armature circuit, whilst the direct-current supply to the field coils is broken since the switch rests on a dummy stop d .

A further safeguard may be added (but is not necessary on ships' installations where the voltage is unlikely to vary greatly) to prevent the motor being overloaded. This consists of a

second electro-magnet m_2 which attracts an armature mechanically connected to a trip device T. If too great a current passes through the armature this trip device is actuated, owing to the increase in the electro-magnet's attraction, the horizontal portion of the starter handle being released under control of a spring (which can be set to release the handle at any desired voltage and so control the device), and the movable portion of the handle flies back to the rest position. Fig. 211 shows the connections of the usual starter. All starters of this type have three terminals usually marked M, L, and R, for connection to the field coil (Magnet), one of the mains (Line), and armature (or Rotor) R, and hence back to the other main.

In order to economise space and reduce the number of operations many ships' wireless installations are fitted with "combined" starters and speed regulators, i.e. a single instrument to carry out both operations.

These contain at least four terminals and perhaps more. If a diagram of connections is not available, those who are inexperienced may find great practical difficulty in elucidating the correct method of connection.

All such combined starters will be found to cause four actions according to the position of the handle (see Fig. 212), namely—

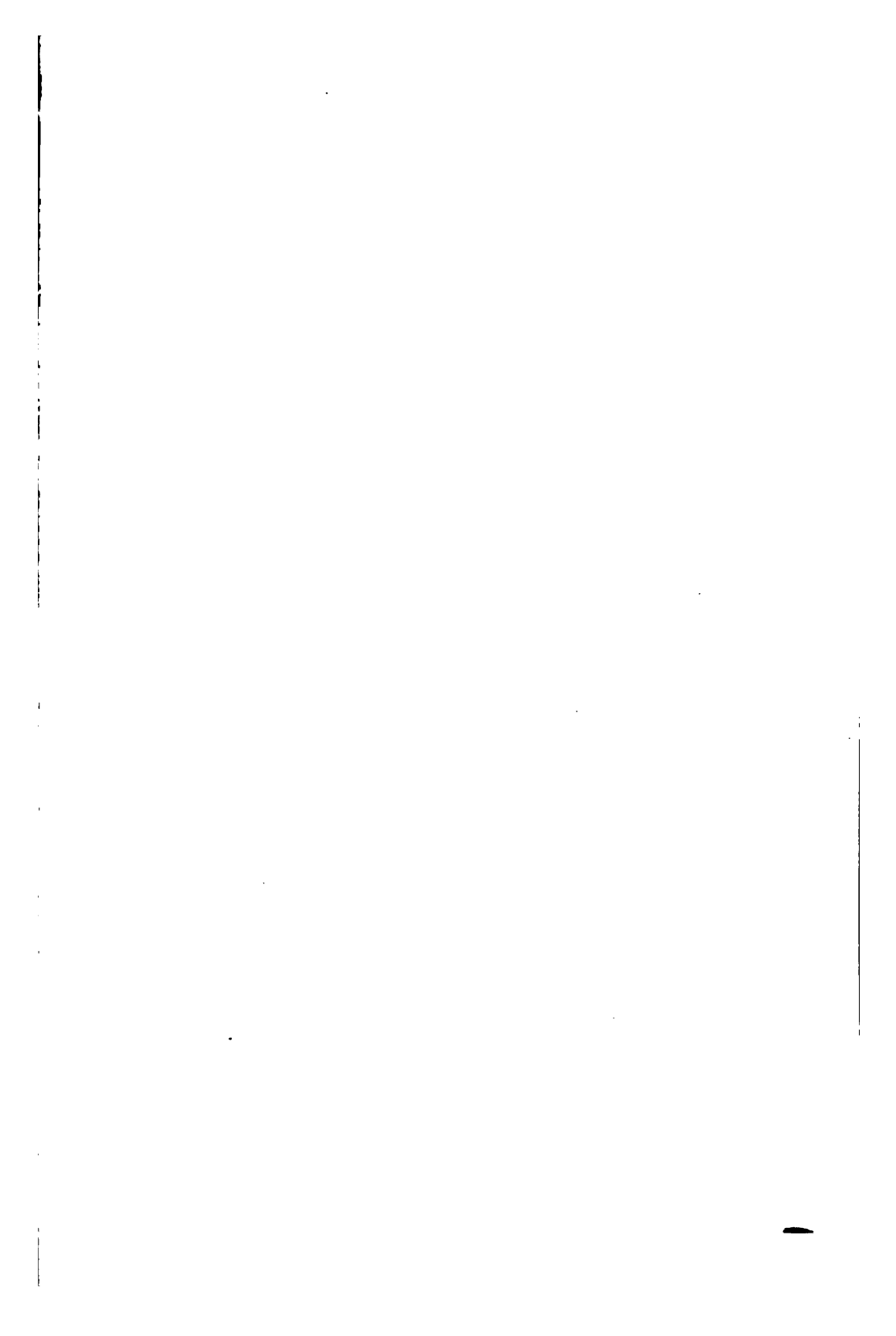
1. At the rest position on the first stud all circuits are broken.
2. On moving the handle to the right, as soon as the first working resistance stud is reached, a small magnet coil is energised and closes the starting resistance circuit R'. This magnet also acts as a safety device, since should the current from the mains be broken, it is de-energised and the handle flies back to the rest position, putting all the starting resistance in the armature circuit.

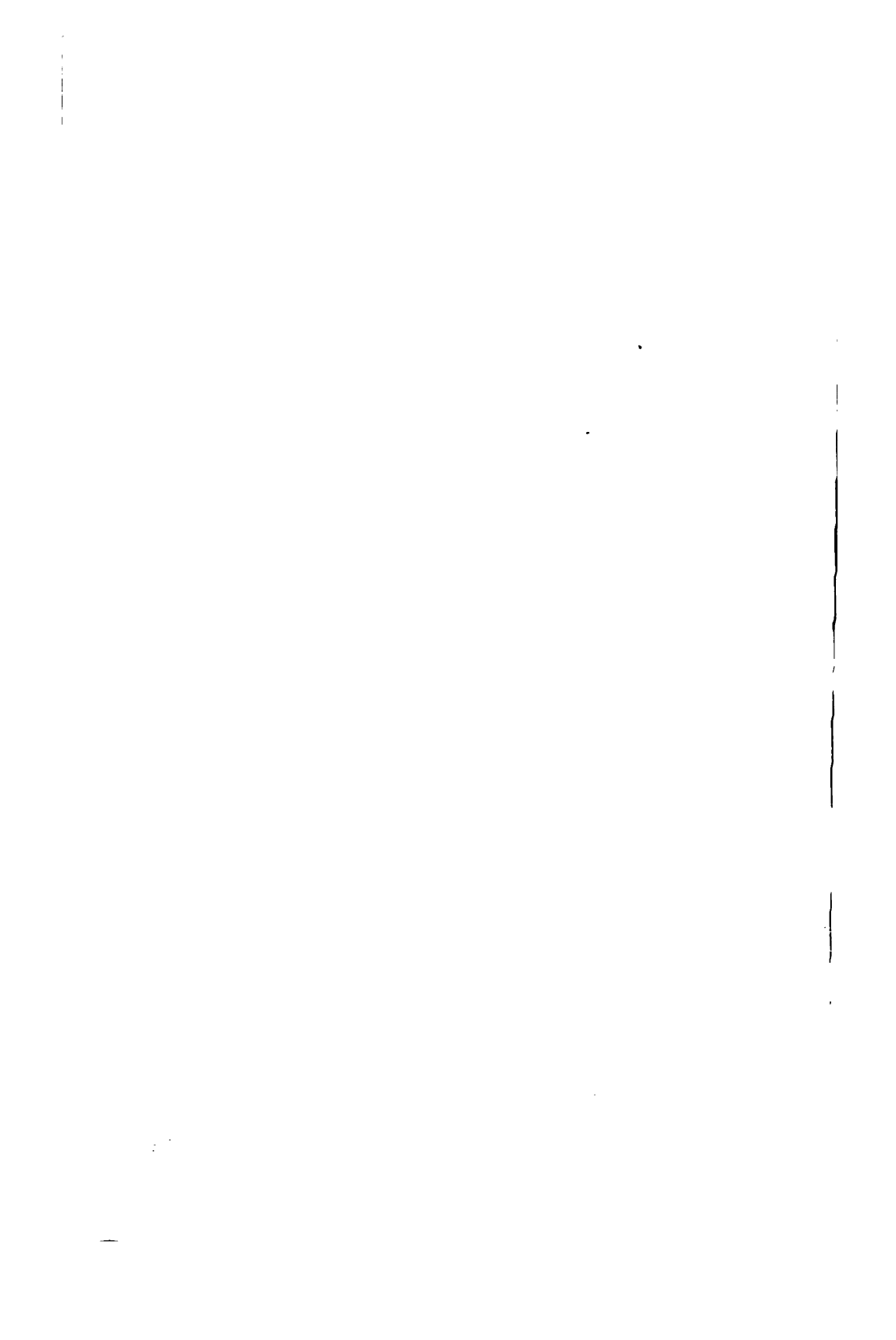
3. Further movement from stud to stud cuts more and more resistance R' out of the armature circuit, until it is all cut out and the motor is running at its normal speed.

4. Still further movement, by means of the connections shown, puts resistance R'' in the field coil circuit and thereby increases the speed as already described.

With the particular example illustrated the terminal 3 serves (when the starter is used for a motor generator), to connect the alternator field coils. This ensures that current only flows through the alternator field windings when the motor is running and it can so serve a useful purpose.

All forms of combined starters by any manufacturer will be found to be as described, but the actual method of closing the no-





volt release may be found to differ. In some types the circuit is made by a cam, in others the movement of the handle directly closes the two contacts, which complete the circuit.

Automatic starters are unlikely to come within the sphere of the ship's wireless operators. These permit the starting of the motor by pressing a small push and stopping the motor by pressing a second push. This allows distant control, so that a large machine can be placed some distance away and noises due to its continual running will not be objectionable during wireless reception.

This is obtained by connecting the starting switch to a small motor which is itself small enough not to need a starter, and therefore can be directly started by a push button. This motor rotates the starter handle. In order for it to do this slowly, it is usual to fit some damping device (such as a fan, offered great resistance to its motion by the air) to the armature of the small motor. Except for this, the connections are similar to an ordinary starter, and the switch gradually rotates over the resistance contacts, until all resistance is put into circuit when the small motor's circuit is interrupted and its rotation stops, whilst the starting handle of the large motor is held over by a solenoid. To stop the large motor, a second stop is pressed, causing a reversed current to flow in the solenoid, which so fails to attract the starting switch, and this under a spring control, flies back to the rest position.

Such automatic starters are frequently installed in land stations, where, because of a noisy petrol engine, it is desirable to place this, with its connected generator, at a distance in order that it does not interfere with reception of messages. This distant control dispenses with the necessity and loss of time in signalling to the engineman, who may even be dispensed with. It is only rarely automatic starters are fitted on ships' installations.

As regards the actual maintenance of starters and regulators, the necessity of keeping these clean is very great. They are mounted upon the wall and the resistance coils are in an iron frame, having ventilation openings, in order to permit the air to come into contact with the heated resistance coils.

These openings also permit the ingress of dirt, etc., so that after a long period there may be a sufficient accumulation of dirt to cause a short-circuit and possibly serious damage to the motor. Hence they should be occasionally inspected and any accumulated dirt removed, preferably by a bellows, *never by means of a steel*

instrument before making certain the direct-current switch on the switchboard is open.

The movement of the starting switch across the studs should never be too rapid, or too great a current will be taken and the direct-current ammeter burnt out. When a fault has to be located in a starter (which should not normally be necessary to the operator), it is a useful tip to disconnect (after marking) all connections since otherwise a circuit will be made through the motor itself and a starter circuit which is really broken will show apparent continuity, owing to the circuit via the motor.

Ammeters and Voltmeters.—These should never be interfered with by the operator, except to keep their cases clean, and to tighten up any connecting nuts to the switchboard if they should work loose.

They are usually supplied with protective fuses. If one of these is burnt out, it must be replaced by one of the special fuses supplied.

If an instrument is burnt out, as by too rapid starting of the motor generator, nothing can be done except in an electrical laboratory having facilities for recalibrating the instrument.

In such a case the operator's only recourse is, until return to a port, to *short the ammeter*, if this is burnt out, by a stout copper wire or strip. If, however, the voltmeter is burnt out *it must not, under any circumstances, be shorted.*

When either instrument is burnt out, extra care is called for in starting and running the motor generator, since the controlling instruments are then lacking and the motor may more easily be damaged.

The Morse Key.—The Morse key contacts should be attended to from time to time and if necessary filed smooth with a *dead smooth file*, as little of the expensive platinum contact being removed as possible. When in course of time all the metal is worn away, a new contact, from the spares supplied, must be fitted before the brass key lever is damaged by sparking.

In order to suit the operator's personal convenience the distance apart of the contacts, and hence movement of the lever, can be adjusted by the screw at the back of the key.

The Transmitting Relay (Figs. 27 *a* and *b*).—This normally requires little attention, but to ensure easy working, the merest trace of oil may be occasionally put upon the guide bars and the working surface of the armature.

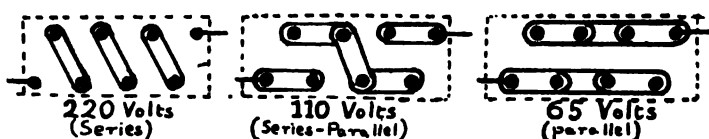
The spring, which redraws the armature down, may be adjusted to give a fairly quick return. The best working is

obtained when both contacts just make equal and firm contact, without excessive knocking together. Such knocking, if excessive, not only gives a bad contact, since the excessive momentum causes them to rebound, but also tends to loosen the nuts. Any loose nuts should be tightened up.

The contacts may, if necessary, be filed flat. They should not wear out until after a very long period, when they may be replaced from the spares supplied.

The connections for correct working, with different voltages of supply, are obtained by means of terminals and short-circuiting copper strips above the magnet coils.

The correct connections are as follows:—



and after the correct arrangement has once been selected by the installing engineer, should not be altered by the operator, as either the magnetic traction of the armature will be too small or overheating of the magnet coils will result.

Cleaning, to prevent rotting of the windings and shorting between the various terminals, apply to this part of the apparatus.

The Choke Coil.—Requires no attention other than cleaning on the part of the operator. It is usually made variable by an arrangement of terminals such as just described, the best arrangement to give low frequency resonance between primary and secondary circuits being selected upon installation.

The Transformer.—This is foolproof and in the event of a breakdown can only be rewound by experienced electrical engineers.

Breakdown will be prevented if sea water and dirt are not allowed to get at the windings, and for this purpose it is totally enclosed.

If a safety spark-gap is provided across the secondary winding this must not be tampered with.

Should it be found to become excessively hot, i.e. hotter than can be easily borne by the hand, it will be best to run the installation as little as possible until return to port, in order that the main transmitter is not placed totally out of action.

If a "megger" is available from the ship's electrician the insulation should be tested between :—

- primary and secondary (7800 volts),
- primary and earth (the iron case) (220 volts),
- secondary and earth (the iron case) (8000 volts).

The figures given are for a normal 1.5 T.K. or "D" station and at normal temperatures should be exceeded threefold for five minutes. For reliable working without the fear of a breakdown they should withstand an overload at least twofold.

On the larger transformers at land stations it is a common practice to earth the secondary winding at one pole through an inductance. This ensures the prevention of sparking between the secondary and iron case of the instrument. Passage of oscillatory current to earth is prevented by the presence of the inductance.

THE EXCITATION CIRCUIT (Fig. 29 *a* and *b*).

The Inductance.—Little can happen to this except wilful alteration of the wavelength sockets, which will necessitate re-tuning by means of a wavemeter.

Keep it clean and dry or the plating will perish, and if this is silver the skin resistance will rise and therefore the damping.

The Condensers.—Keep the contacts clean and with Leyden jars watch out and remove any excessive sparking at sharp edges of the foil coats by the application of shellac. Any sharp edges should be removed.

With oil condensers see the plates are well covered with the special oil supplied and do not attempt to alter the safety spark-gap when once adjusted, or breakdown may result.

The Spark-Gap (Fig. 17 *a*).—This should not need attention more than once a month in normal ship stations. In land stations, when heavy traffic is being dealt with, the cooling fan should be used to prevent arcing, with consequent volatilisation of the silver facing.

About once a month, after their removal from the supporting frame, any heavy deposit should be wiped off the sparking surfaces with a rag or brush. When after long use they are found to be deeply scored or pitted, they should be polished.

For this purpose a cleaning apparatus is provided. This consists of two flat steel plates each with an inner planed surface. The outer surfaces have a raised cross so that they are easily grasped in the hand.

One plate on its inner planed surface has a circular depression which will just take the spark-gap plate with its silver face outwards. The other plate is covered by a sheet of Paris red, or fine emery paper, and the silver face of the spark-gap is polished smooth and flat, by relative motion of the two plates, one in each hand. This provides an easy means of both cleaning and truing the silver surfaces.

In order to obtain a uniform sparking distance between the spark-gap plates, allow them to centre themselves by tapping the stand whilst loose. Having replaced any cracked or injured mica discs, screw them up by means of the tommy bar, which works a pressure screw acting upon the pressure disc. Adjust the distance apart by varying the pressure, until the best aerial reading is obtained, which will show the best quenching effect, dependent upon the distance between the plates, is occurring.

THE AERIAL CIRCUIT.

The Variometer or Lengthening Coil (Fig. 32 *b*).—The remarks as to excitation inductance apply equally to this.

The Shortening Capacity (Fig. 34 *a* and *b*).—Keep this clean and normally out of circuit by the short circuiting bar, which should make good electrical contact.

The Aerial Ammeter (Fig. 35).—The previous remarks as to low-frequency instruments apply equally to this, and as it is a specially constructed instrument it is far more expensive to repair. On a 1.5 T.K. station it should show at least 16 to 20 amperes without the shortening capacity and about 4 to 8 amperes with this capacity in circuit, which greatly reduces the efficiency.

Do not overload the aerial and so burn this instrument out. If this occurs it may be removed or shorted, but correct tuning is then not ascertained, unless it is possible to obtain a low-resistance lamp, place it in the aerial and tune by maximum illumination. This is unsatisfactory since an exact quantitative reading is not given and the aerial oscillations are greatly damped.

Only specially equipped laboratories for high-frequency work can correctly recalibrate these instruments, but, as only a comparative reading is usually required, this is not of excessive importance.

The Aerial Lightning Switch (Fig. 38).—This should always be kept closed when the station is not working. Before leaving his station when in port, etc., the operator should always see :—

1. The D.C. switch is open.
2. The receiver switch opened.
3. The lightning switch is closed.

The safety spark-gap of the latter switch having been once set, do not attempt to get greater aerial current, by opening it to a greater distance, or the aerial ammeter may be burnt out.

The Leading-in Insulator (Fig. 40 *a* and *b*).—This requires periodical cleaning, taking it to pieces if necessary, as described in Chapter III.

The Aerial.—This should be kept strained up as tight as possible, which not only prevents any kinking in the leading-in wires, but also gives a more constant aerial and therefore constant wavelength by the prevention of relative motion and consequent capacity changes in relation to the masts, etc., together with a greater mean aerial height and hence increase of range. Since its capacity is greater, more energy can be put into a well-strained aerial.

If it is necessary to take the aerial down, care must be taken that it does not kink, with consequent breakage on again raising it. From time to time it should be lowered to replace or clean the aerial insulators.

The correct method of joining the aerial and lead-in wires has been illustrated on page 243. All connections should be sweated to give good electrical contact. All free ends, if they cannot be entirely avoided, should be sweated into small metallic balls, provided in the spares, to prevent brush discharge.

Before dirty weather, if possible, the aerial should be inspected to see that there is no apparent likelihood that it may be carried away, and in its fall be a danger to those on deck, besides interrupting wireless communication when it may be most necessary.

THE RECEIVER (Fig. 44 *a* and *b*).

It is of the utmost importance that the receiver be kept clean and free of dust, and that oxide or verdigris be not allowed to form on the metal parts. When the installation is not in use, the detectors should be disconnected by turning them half-round in their sockets, or removal from their plug sockets, and the switch should always be turned to the "Transmitting" position.

If detectors become insensitive they should be adjusted in the following manner:—

TYPE E.D. 23. Remove the cap. Insert the slip of emery cloth (inside the cap) between the molybdenite and the spring—

the emery facing the molybdenite—and draw it gently through, the detector will then be found to be restored to its original sensitiveness.

TYPE E.D. 39 or S.B. 13. Remove the cap. Slacken the screw which adjusts the contact between the crystal and the contact wire. Turn the crystal so that a fresh part of it comes opposite the wire and then tighten up the screw till the wire comes in contact with the crystal. By adjusting the screw, find the correct pressure between wire and crystal to give the highest degree of sensitiveness.

Spare detectors should be kept by themselves as far from the transmitter as possible, *not* thrown into a drawer with tools, spare parts, etc.

Any loose connections on the receiver should be tightened up to ensure good electrical contact.

THE EMERGENCY TRANSMITTER.

Other than the change-over switch and special connections on the switchboard, including the circuit breaker, this consists of the induction coil and emergency battery.

The Induction Coil (Fig. 21), whose operation is given later, requires little attention except protection, by always keeping its case closed, and occasional clearing and oiling to prevent corrosion of the metal.

As with the Morse key, the platinum contacts must be smoothed up from time to time, or exchanged if necessary.

The Emergency Battery.—Experience in the efficient maintenance of accumulators can only be obtained by practice, and it is advisable to refer to some good electrical text-book in order to obtain some knowledge regarding electrolysis and to thoroughly understand the physical and chemical actions which occur.

In practice, on British ships fitted on the Quenched-Spark system, two types of accumulators are to be found:—

- A. The ordinary Lead/Sulphuric Acid Battery.
- B. The Edison Nickel/Alkali Battery.

All those ships, which are in the large majority, fitted in Great Britain itself, employ the first type of battery, but in the case of a considerable number of British ships, which were “on station” and entering American and not British ports, Edison batteries were installed by the American agents.

Instructions for the Installation and Maintenance of Hart Accumulators.—Most electrical text-books describe the general

reactions and method of construction of the lead accumulator, so this will not be further dealt with here.

For the convenience of operators, so that they may have instructions for maintenance at hand, the instructions given by the manufacturers of the Hart accumulators, which are usually installed in Quenched-Spark wireless installations, are reproduced by permission of the manufacturers.

These instructions will be found to apply equally well to most other lead accumulators, with the exception that the charging and discharging currents may vary.

1. *First Charge.*—It is very important that the process of charging be commenced immediately after the acid is added and continued for not less than 36 to 40 hours at the normal charging rate. On no account should the dynamo be stopped for the first 12 hours, nor should the battery be used to supply current until gas is being liberated freely from both positive and negative plates in each cell and the specific gravity of the electrolyte and the voltage cease to rise any further. The specific gravity of the acid will drop when it is first put in the cells and may not commence to rise for some considerable time after the charging has started. If at the end of the first charge it rises above 1.210, pure *distilled* water must be added to reduce to 1.205 to 1.208. The water must be well mixed with the electrolyte to obtain uniform gravity throughout and should be added before the charging is stopped. Never add natural water containing sulphates, which combine with the lead plates and so injure the cell's action.

2. *The Rate of Charge.*—For the usual "T.Y.L. 7" Hart cells, supplied for wireless emergency sets, the maximum discharge rate is 12 amperes, maximum charging rate 15 amperes, and normal charge or discharge rates are 8 amperes in each case. It is therefore seen that, if necessary, the normal discharge rate can be increased 50 per cent. and normal charging rate nearly 100 per cent. if occasion warrants. A slow steady charge or discharge is however better for long life of the cells and efficient working than a rapid heavy one, and the normal rate of discharge should not be exceeded if possible.

3. *Charging.*—Cells should be charged as soon as possible after each discharge is completed. They should be fully charged when the number of ampere hours put in exceeds those taken out on the previous discharge by 10 per cent. A 90 per cent. efficiency is thus obtained and daily records of the meter readings should be kept. If the battery is charged every day a 95 per cent. efficiency may be obtained.

4. *Starting Dynamo.*—Before the battery is put into circuit care must be taken that the correct e.m.f. is being generated. Automatic cut-outs are a safeguard against any great difference from the correct voltage.

5. *Stopping Dynamo.*—The battery must be cut out of circuit before the dynamo is stopped, or the battery will discharge through the windings of the dynamo. The automatic cut-out fitted, if working properly, ensures this.

6. *Covers.*—Evaporation of the electrolyte is greatly retarded by use of glass spray arresters covering the top of the plates. These must be easily removed for purposes of examination. These also prevent the ingress of harmful sea water.

7. *The level of electrolyte must never be allowed to fall below half-inch*

above the top of the plates, as it is essential these be kept well covered or the exposed portions will be sulphated. Any loss must be made up by adding pure *distilled* water at the end of the charge when the plates are gassing. The water must be well mixed with the electrolyte. Acid, other than that supplied by the makers must not be added unless it is guaranteed pure sulphuric acid of correct specific gravity.

8. *Testing.*—The condition of each cell should be tested by a pocket voltmeter from time to time and should be at the end of discharge, 1·8 volts per cell, normal current passing. The voltage of each cell should also be tested at the end of charge, and readings taken ten minutes before the charge is stopped. Any cells which indicate lower than the others should be specially examined for internal contacts and cut out of the discharge circuit (whilst in circuit during charging) for the next two charges, or until recovered. The specific gravity of the electrolyte should be tested once a week at the end of a charge and the plates in each cell carefully examined from time to time. Any internal contacts across the plates must be at once removed.

9. The specific gravity of the electrolyte on a full charge should be 1205 to 1210, at 60° F. (15° C.) An increase of temperature above 60° F. will result in a lower specific gravity in the proportion of 1° specific gravity for a 3° F. rise. Similarly 1° specific gravity rise results for each 1° F. fall. Thus if it is 1205 at 60° F. at 69° F. (20·5° C.) the specific gravity is 1202 and at 51° F. (10·5° C.) it is 1208.

10. *Irregularities.*—Any cell which does not gas freely at the end of a charge; must be carefully examined for internal contacts caused by scale, etc. These must be immediately removed and the cell given an extra charge. In the case where cells are joined together by terminals the simplest way to give this extra charge is to cut it out during discharge and to reconnect it during several charges. To do this completely remove the defective cell by uncoupling its terminal connections and connect, by a flexible insulated cable, the terminals of the adjacent cells. The injured cell can of course be left in situ but *must not be shorted by the connection between the adjacent cells.*

In the case of cells whose terminals are lead burnt together extra charge can only be given by a small booster. Since these are not used on board ship it is hardly necessary to give further details.

11. If the cells are to be left out of work any length of time *the acid must not be removed*, but the battery must be previously fully charged and care taken the plates are well covered by electrolyte. If practicable when not working, a short charge should be given about once a fortnight until gassing occurs, by which treatment they will keep in order for a very long time. Leakage of current is prevented if all connections are disconnected.

Edison Accumulators.—In this more recently developed secondary battery, the electrodes consist of grids of nickel peroxide (NiO_2) for the positive plate and finely divided iron for the negative plate in a 20 per cent. solution of potassium hydroxide (KOH). During discharge the nickel loses oxygen which passes to the iron of the negative plate and oxidises it.

The mechanical construction of the cells is such as to give great independence against rough treatment.

The positive plate is built up from a series of perforated nickel steel tubes, specially wound from rolled strip. Each tube

alternately contains many hundred layers of nickel oxide and nickel plate, well rammed, so giving a hard mass but which is porous enough to allow diffusion of the electrolyte. The tube is double-lapped seamed, and encircled by eight steel bands to ensure electrical contact and to prevent bursting. Thirty such tubes are then mounted in a nickel frame giving a very light structure as compared to the plate of a lead-sulphuric accumulator, and capable of withstanding a great deal of injurious vibration. The negative plate is made of steel and has a large number of lozenge-shaped pockets, made by steel strip, which contain iron oxide. These pockets are subjected to great pressure in order to make the whole mass coherent.

The plates are usually enclosed in a nickel steel case (but insulated) which further enables the cells to withstand very rough treatment, although with this arrangement it is very necessary for the cells to be insulated from each other to avoid leakage currents. When exposed to sea water, this metallic case is a disadvantage of Edison cells.

Instructions for Working Edison Accumulators.

A. Installation.

1. Edison cells are delivered uncharged and with separate electrolyte and are to be filled in the place of erection. The first charge should be for 15 hours with normal current strength.

2. When Edison cells are delivered filled and charged it is possible that during transport some of the liquid will be spilt. Before installation it is therefore necessary to inspect all cells, and if the plates in each cell are not covered by a height of 12 mm., they must be filled with distilled water. If, after the next charge, the concentration of the electrolyte is beneath 18 per cent., then the cells in question must be completely replenished with electrolyte of 21 per cent. concentration supplied by us.

B. Instructions for Maintenance.

1. The battery consists of 26 cells Type P. 27.
2. The capacity amounts to 58 ampere hours.
3. The discharging voltage at a discharging current of 15 amperes amounts for each cell to 1.23 volts, for the 26 cells 31.98 volts.
4. The discharging current is 15 amperes. It is permissible to discharge with a higher current strength for short periods. *It is not permissible to frequently exceed the normal discharging current strength.*
5. The battery is discharged when, with a current strength of 15 amperes the voltage sinks below 1.1 volts per cell, that is, the total voltage for the battery sinks beneath 28.6 volts.
6. The charging of the cells when in series is carried out with a normal current of 22 amperes and lasts for 3 to 4 hours. With batteries which have

remained unused for some time a further charging of at least 15 hours with two-thirds the normal charging current strength must be given.

7. If the cells are charged with less than 22 amperes the time of charge is increased accordingly. The cells must not be charged beneath 7 amperes, that is, one-third the normal current strength.

8. That the charging has been completed is indicated if the voltage at normal charging strength rises or exceeds 1.8 volts per cell, and remains constant for about 40 minutes.

9. It is not permissible for the temperature of the cells during charging to exceed 50° C. and 55° C. during discharge. The best results are obtained when the temperature of the cell is between 25° C. and 43° C.

10. The electrolyte consists of a 21 per cent. caustic potash solution, the concentration of which may vary between 18 and 22 per cent. *For replenishing pure distilled water only must be used.*

Drinking water must never be used.

Under no circumstances must sulphuric acid be used for refilling Edison cells, or an accident may result.

11. After about 250 discharges, or at least after working for eight to nine months, the caustic potash must be completely renewed.

12. The openings of the cell for refilling are fitted with a trapdoor cover. It is necessary that this cover remains closed except for the short time during which the cells are being refilled. The entrance of air destroys the cell. Naked light must not be brought into the neighbourhood of the cells.

13. If the battery is built into a special case, during the charging of the cells, the case must be open in order to permit the escape of the gases evolved.

14. The wooden case must be kept dry to prevent the passage of current between the cases of the cells. The connections between the poles of one cell to another must also make good contact.

Comparison between Lead and Edison Accumulators.—

In the author's experience the later developed Edison cell has great advantages over the lead accumulator, but it is only fair to mention that this preference is not held by many who have used both types.

The chief relative advantages and disadvantages are given below:—

A. Lead Sulphuric Accumulator.

1. Rapid discharge causes paste to drop out, and buckling.
2. Continued discharge causes sulphating.
3. Overcharging causes disintegration of plates.

B. The Edison Accumulator.

1. Having no paste rapid discharge has no effect, and cannot cause buckling.
2. Continued discharge does not permanently affect the cell, since an inert body, as lead sulphate, is not formed and the cell may even be charged in reverse direction without permanent injury.
3. Overcharging cannot disintegrate the plates, owing to their mechanical structure.

4. Even if not in use, lead accumulators require periodical recharging, in order to remove the sulphate slowly formed by chemical reaction.
5. Must be charged at a low rate, to avoid disintegration and buckling.
6. Specific gravity of electrolyte must be constantly tested.
7. Temperature must be kept within certain limits.
8. Cells cannot withstand vibration as it causes disintegration of plates.
9. Acid fumes are given off so that accumulators cannot be stored near any machinery, etc.
10. Whilst sea water on the cases is injurious, since the case is a non-conductor (wood), this is not of such great importance as with Edison cells.
4. Periodical recharging when at rest is unnecessary for the cells preservation, but they have a tendency to reverse their polarity if not periodically charged.
5. Owing to mechanical structure buckling cannot occur. Upon emergency, cells may be charged, for short periods, at five times the normal rate.
6. Specific gravity of electrolyte is not so important.
7. Temperature variations comparatively unimportant.
8. Vibration, owing to mechanical structure, cannot cause disintegration.
9. No acid fumes are given off.
10. If wet by sea water the metal cases act as conductors, short circuits occur from case to case and the cells discharge.

Both types evolve hydrogen, which is very explosive so that naked lights should never be used whilst inspecting batteries.

The Charging Switchboard.—On most ship stations the charging switchboard is usually combined with the main switchboard. Such combined switchboards have been nearly exclusively installed of recent years, since the necessity of an emergency installation is nowadays so apparent, that for most ships it is compulsory.

On some of the earlier installations which have since had separate emergency sets installed to comply with more recent regulations, and on small ships which are not compelled to carry a wireless installation but it is nevertheless preferred to install a small installation working from batteries, a special battery charging switchboard will be found. Moreover, those who find difficulty in mastering the combined form of switchboard will find it easier if they first master the separate battery switchboard, which is of general use in all cases in electrical work where batteries have to be charged and for this purpose is often installed at land stations.

The connections of such a board are shown in Fig. 213.

It consists of an ammeter and voltmeter of which the latter may, by movement to the left and right respectively of the small centrally placed instrument switch, be put into either the charging circuit through the double-pole double-throw switch S' or in the discharging circuit through the similar switch S''.

The mains, from which the charging current is to be obtained, is led through fuses A' to the switch S'.

When both switches are placed downwards the current passes through the circuit breaker to the battery.

The ammeter is included in circuit to indicate that the correct amperage is being obtained. To regulate this a variable charge-

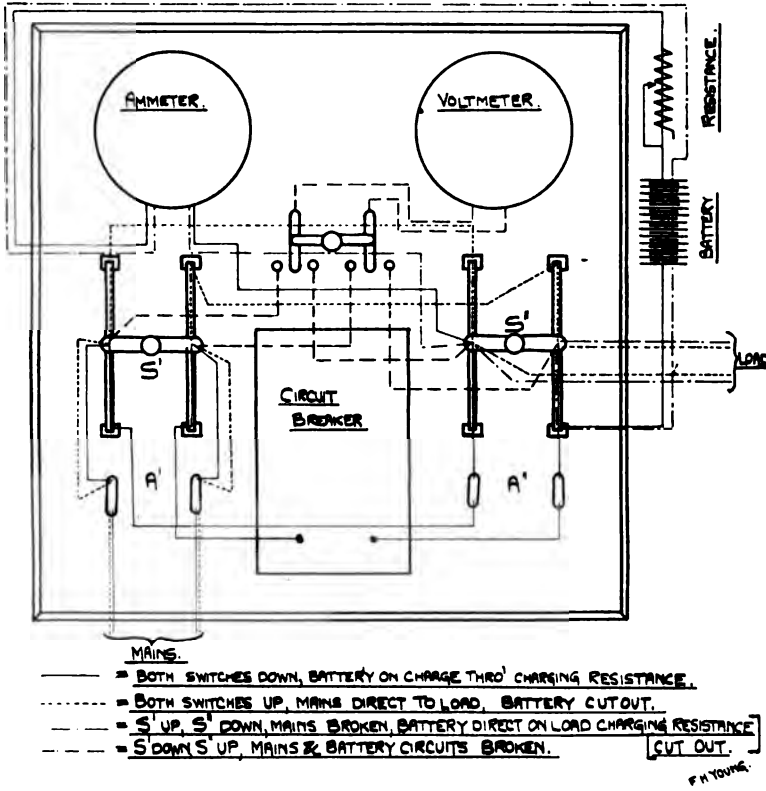


FIG. 213.—Battery charging switchboard.

ing resistance is inserted in the external circuit. The circuit breaker is merely a solenoid, through the windings of which the charging current passes and hence to a pair of stout metallic contacts, one of which is mounted upon the armature of the solenoid, and the other is rigidly mounted on the switchboard.

When the switch S' is in circuit, the contacts of the circuit breaker are closed by hand and the solenoid then causes them to

remain closed. Should the current stop, the solenoid is de-energised and the pair of contacts are opened by means of a spring control, the circuit being so interrupted until the circuit breaker is again intentionally closed by hand when current is again passing.

The circuit breaker also serves to prevent unnecessary passage of current from the mains to the battery if this is fully charged. When the battery is discharged it takes a heavy current from the mains, which by its effect in the solenoid keeps the circuit breaker closed. As it becomes charged the current falls off, and when fully charged, since its e.m.f. nearly completely opposes the charging mains e.m.f., the resulting current flowing is small. The solenoid is therefore not so greatly energised, and the spring control, acting against the magnetic force of the solenoid, pulls the circuit-making contacts apart. This spring control when once properly adjusted should not be tampered with. This permits the battery to be put on a long charge and left without attention. Without a circuit-breaking device this could not be done, since the battery would totally discharge through the windings of the charging generator, and the battery would be ruined if this should be stopped.

This switchboard also permits the wireless transmitter to be worked directly from the charging mains should the battery be, by long use, discharged. For this purpose both switches are put in the upper pairs of contacts.

To work the installation from the battery after this is charged, the switch *S'* is placed in its upper sockets so breaking the mains, and the switch *S''* in its lower sockets so completing the discharging circuit via the fuses *A''*. The charging resistance which would unnecessarily consume energy is now cut out.

To break both the mains and battery circuit when it is not wished to either use the wireless transmitter or to charge the battery switch, *S'* is placed downwards and Switch *S''* upwards.

To those without much practice of switching arrangements, the diagram given can be very usefully studied for general information regarding switching. The particular board in question is becoming of more interest since, with the smaller Quenched-Spark stations, fitted in ships only requiring a limited use of its wireless apparatus it is becoming the practice to work the small motor generator off the emergency battery instead of the mains in order to ensure that this battery will be always ready for emergencies and not suffer neglect by the operator always working his installation off the mains.

5
1
1
3



FIG. 214.—Quench-spark station on the S.S. "Chindwin" (the Henderson Line, Ltd.).
[To face p. 451.]

B. OPERATION.

(Numbers refer to Figs. 214 and 215.)

A. TO TRANSMIT ON MAIN SET.

(All switches open on switchboard.)

The motor, 6, of the motor generator set must first be started. To do so:—

1. Close D.C. switch, 2, after having made certain the starter handle, 5, is in the "off" position, and the handle of the speed regulator, 9, in the starting position to the left.

2. Observe the voltmeter, 4, when the voltmeter switch on the switchboard is turned to the left, and see that excessive voltage is not obtained across the D.C. mains. If it is below the normal voltage endeavour to get the engine-room generator speeded up to give correct voltage.

3. Gradually move the starter, 5, over to the right. Do not do this too hurriedly, and control the speed by observing the ammeter, 3. When fully over see that the magnetic "no volt release" is made.

4. Adjust the speed regulator, 7, until the most suitable note is obtained (as determined by the use of aperiodic circuit, 34, whilst the sending key, 32, is depressed). This is normally 1500 r.p.m., but may be varied to the distant station's choice of musical note.

5. Insert the A.C. switch, 11.

6. Note the A.C. pressure by the voltmeter, 12 (normally 220 volts) and the A.C. current by ammeter, 13.

7. To obtain the correct A.C. voltage, the alternators exciting current is varied by the resistance, 9, and for a fine adjustment, 9 a.

8. The A.C. circuit is now completed by opening the receiver switch, which should, however, have been left in the open position, when the station was last used.

To Adjust the Wave Length.

9. See that the plugs are in the correct plug sockets on the excitation circuit inductance, 15, and aerial circuit inductance, 19. If the 300 metre wave is to be used, see the shortening capacity, 20, has its short-circuiting clip in the open position, instead of closed as required for the 600 metre wave.

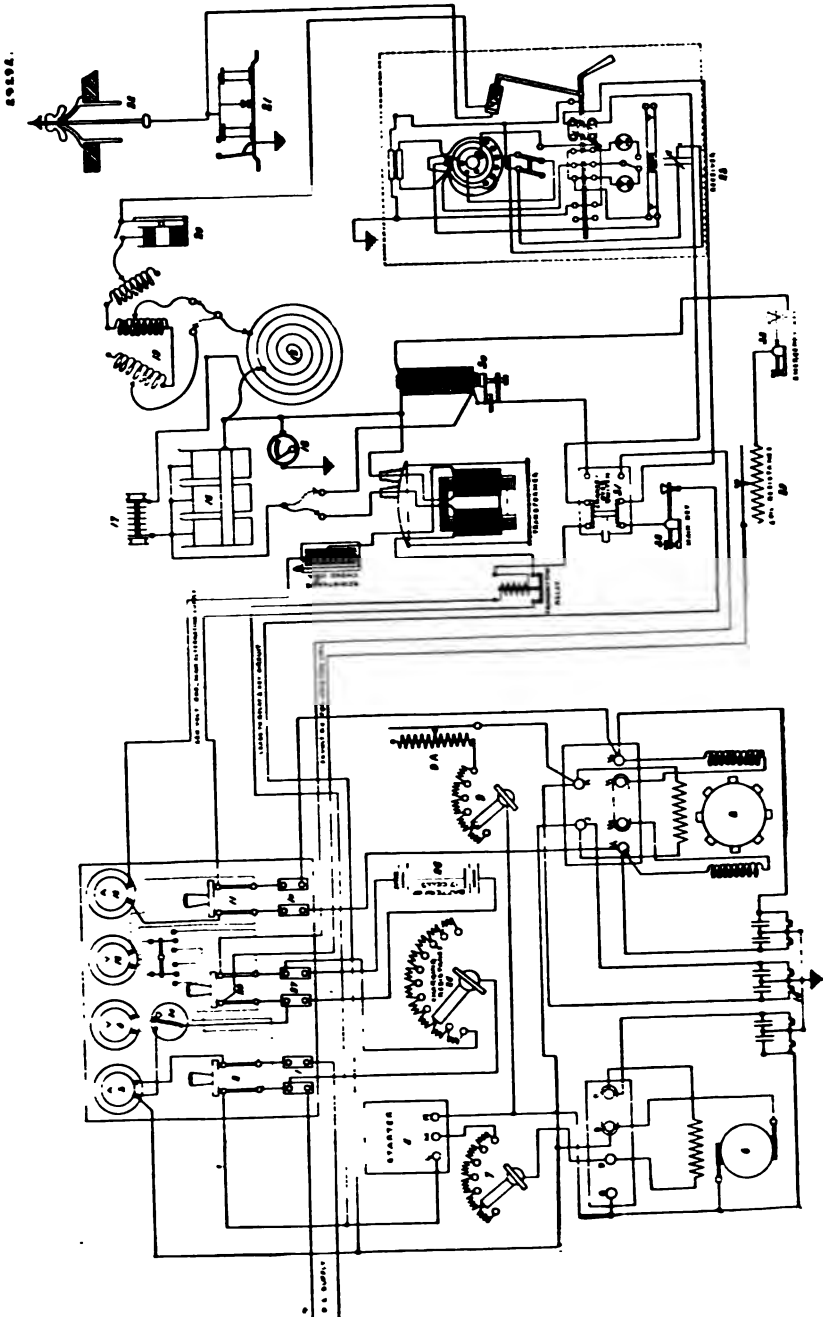


FIG. 215.—Connections of station on S.S. "Chindwin".

10. Open the correct number of spark-gaps, 17, by removing the short-circuiting clips. The larger the number of gaps used, the greater will be the aerial current and range of transmission.

11. Open the lightning switch, 21.

12. Depress the key, 32, and vary the movable coil of the aerial variometer, 19, until the aerial ammeter, 18, shows the maximum reading.

The installation is now ready to send. After opening the switch, 21, do not press the key more than absolutely necessary to avoid jamming other stations.

B. TO TRANSMIT ON THE EMERGENCY SET.

(All switches open on switchboard.)

1. Turn the small switch to the right, so that voltmeter, 4, is put across the battery switch, 28, and see that the correct voltage (32 volts or just above) is given by the battery, 26.

2. Close battery switch, 28.

3. Turn change-over switch, 31, to "emergency" set position, i.e. to the right.

4. Depress the emergency set key and adjust hammer of induction coil, 30, whilst varying the induction coil resistance, 29.

5. After this, the adjustment of the excitation and aerial circuits is as from (9) of the last section. After having tuned the station it may be an advantage to readjust the induction coil resistance, 29, to give maximum aerial reading, which will be much less than when using the main set.

The Adjustment of the Hammer of the Induction Coil.

—It must first be noted that the distance m (Fig. 216) between the hammer h and the core k must be about 2 to 3 mm. If this is not the case the nuts n and o must be loosened and this distance adjusted. As soon as this distance is correctly adjusted the nuts must be tightened up again. The lock nut b should then be released and the screw a to which the spring c is connected must be turned back so far that the two platinum contacts d and e do not touch. The platinum contacts should be in a carefully polished condition and their surfaces must be exactly parallel. The Morse key being depressed, the screw a should be slowly screwed forward. As soon as d and e are in contact the current can be increased by cutting out the induction coil resistance until the hammer vibrates properly. As the current

is increased the contact *d* can be screwed up further by means of *a*, but as soon as violent sparking occurs it must be screwed somewhat back. This adjustment should be made *with two or three spark-gaps* and with the aerial correctly tuned. If the hammer works satisfactorily the tone should be checked by means of the aperiodic circuit brought in the neighbourhood of the transmitting antenna. The hammer will always spark if the note is impure, i.e. if the excitation of the induction coil is too strong in

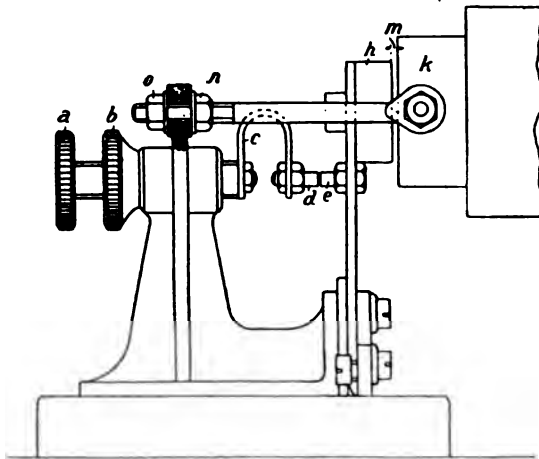


FIG. 216.—Details of induction coil hammer-break.

proportion to the number of spark-gaps to be bridged. If it is desired to work with reduced spark-gaps, the pressure between the platinum contacts should be somewhat loosened. When the most favourable adjustment of the hammer is found *a* should be locked by means of the nut *b*.

In no case may the hammer *h* strike against the core *k* violently as this gives rise to vibration which detracts from the regularity of the interruptions.

To Charge the Accumulator Battery.

1. Insert the D.C. switch, 2.
2. Insert all the charging resistance, 25, by turning it to the right.
3. Turn the small voltmeter switch to the right to indicate the voltage across the battery.

4. Close the circuit breaker, 24, and hold it closed whilst the resistance, 25, is turned back until the correct ampereage and voltage is shown by instruments 3 and 4, upon which, if the spring control is correctly adjusted, the cut-out circuit breaker should remain closed, owing to its solenoid.

THE RECEIVING CIRCUITS (Fig. 44).

Before reception it may possibly be preferable, if received signals are weak, to stop the (main) transmitter.

To do this the field resistances, 7, 9, and 9 *a*, are turned back to the off-position, and the switches, 11 and 2, then opened, when the handle of the starter, 5, will automatically return to the off-position.

The receiver switch is now closed, by which means the aerial and earth are connected to the receiver and the detector circuit is made.

If the wavelength of the signals to be received is not known, one must proceed as follows:—

The coupling between the aerial and detector circuits should be made as close as possible by turning the detector coil as far downwards as possible. The plug of the inner detector coil is then first placed in the socket marked 1, and the condenser at the base slowly rotated from 0° to 180° until signals are heard. If they are not heard the same process is repeated for socket 2, etc., until signals are heard, upon which the aerial circuit is exactly tuned by rotating the condenser to give signals of maximum intensity.

The outer detector coil is now adjusted by inserting its plug in that socket which gives maximum signals.

The coupling may now be decreased if strength of signals permit, until greatest selectivity is obtained.

If the intermediate circuit is being used to select particular signals it is only necessary to insert the second plug socket in the secondary coil and adjust the extra secondary circuit condenser to requirements.

Unless the adjustments for any particular station to be received are definitely known it is always best to carry out the above operations systematically.

If the wavelength of the opposite station is known, the plugs can be immediately inserted in their correct sockets as determined by their inscriptions, and the condensers can be adjusted, either by trial, or by means of curves supplied if very accurate tuning is desired.

C. POSSIBLE FAULTS.

POSSIBLE FAULTS DURING TRANSMISSION.

1. The Motor Fails to Start.

1. Ascertain that current is being received from the engine-room, in which case instruments 3 and 4 will give readings, the latter being switched over to the left.

2. If no reading is obtained, examine the fuses, 1, after which refer the matter to the engine-room, since the only alternative is that the D.C. supply leads are interrupted between engine-room and wireless switchboard, or energy is not being delivered from the engine-room.

3. If these are in order the defect is either in the starter, 5, or the speed regulator, 7. To ascertain this, the pressure at the motor field windings is measured across terminals DB by means of a suitable voltmeter or resistance lamp.

4. If the motor field windings are tested for continuity after disconnecting the shunted high-frequency device, 14, the only alternative is to test the starter and speed regulator for continuity, for which purpose the diagrams of Fig. 212 will be found very useful.

Before carrying out the lengthy examination of these regulators it will be advisable to examine the brushes to see that these are making contact with the armature and to adjust these if need be. Also it should be ascertained whether the bearings have sufficient lubrication and the defect is merely a high mechanical resistance.

5. Finally make certain the protective high-frequency device, 14, across the motor field coil is not short-circuited, by disconnecting it either from motor terminal A or C, when an immediate improvement will result.

2. The Motor Rotates but the Alternator Shows no Pressure.

The switch, 11, is inserted. If no reading is obtained on instruments 12 and 13 the faults may be:—

1. Either instrument is burnt out, in which case the other will give a reading. If both are burnt out the ammeter (but *not* the voltmeter) may be shorted and the spark should be heard on depressing the key.

2. A break in the regulators, 9 and 9 *a*, which must be tested for continuity, and examined to see that the sliding contact makes good contact throughout all its path.

3. Examine the terminals of the alternator to see these give contact.

4. Test the windings U_1U_2 , V_1V_2 , and JK for continuity.
5. It is possible that the high-frequency safety devices, 14, which are in parallel to the armature and field coils across U_1V_2 and JK may be short-circuited. To test this one side of the device should be disconnected which will soon show whether the defect is at these points.
3. **The Alternator Delivers Energy but no Spark is Heard.**
 1. Examine the transmitting relay to see that the contacts make.
 2. See the change-over switch, 31, is on the correct side.
 3. Make sure all the spark-gaps are not short-circuited by the clips provided. If not reduce the number, by inserting clips, to ascertain whether pressure is present, but is not sufficient to break down all the gaps being used.
 4. If necessary test the choke coil for continuity, and the armature coils of the transmitting relay.
 5. Test both primary and secondary windings of the transformer when this is disconnected, and test between each winding and the case which should not give continuity unless the windings are broken down. Test the continuity between primary and secondary windings which should give a negative result unless a breakdown of insulation is present.
4. **Spark-Gap is Working but no Current is Shown in Aerial Ammeter.**
 1. See that the plugs and plug sockets are correct (see Fig. 31).
 2. See that the lightning switch is open.
 3. If little current is present cut out the shortening capacity and see if this improves it.
 4. Alter the variometer to make sure the aerial is tuned to the excitation circuit.
 5. The only alternative if the above are correct is an earth on the aerial, or wrong connections of the excitation or aerial circuits.

POSSIBLE DEFECTS OF EMERGENCY TRANSMITTER.

(Circuits up to induction coil.)

1. The battery may be run down. Check by voltmeter, 4, with instrument switch to right. There is no ammeter in the discharging circuit, so an instrument burnt out cannot affect transmission.
2. See the change-over switch, 31, is in correct position.
3. Non-continuity present in resistance coil, 29, most possible at its sliding contact.

4. Break in secondary of induction coil. Examine this for continuity. It is unlikely the stouter primary will break down but this may be examined. If the secondary is burnt out the hammer-break will still work, but not should the fault be in the primary. After this the fault must be in the excitation and aerial circuit as for the main transmitter.

POSSIBLE DEFECTS DURING RECEPTION.

1. See the lightning switch, 21, is open and the aerial is connected, and the receiver switch is closed.

2. See the receiver inductance plugs are in the correct sockets and the "long and short wave" switch is in the correct position.

3. Use the tightest coupling between aerial and detector circuit until signals are found and then loosen it if necessary.

4. If signals are not now heard, try each of the two detectors by means of the small detector switch.

5. If the detectors appear to be good but signals are not heard, place the buzzer near the aerial and send by depressing its key. Unless the detector is not correctly adjusted the buzzer signals should now be heard, with either detector in circuit.

6. If signals are still not heard exchange the head telephones for the spare set.

7. If signals are still not heard some fault has been developed in the receiver possibly by accidental injury or something short-circuiting the permanent leads. The only remedy will be to go over them systematically by means of the diagram, Fig. 44. This is not likely to occur, but when it does the first thing to examine is to see that the entrance of the receiver switch into its socket separates the springs which during transmission connect the aerial to earth. The next likely place is good contact of the detector and the "long and short wave" switches.

Reception is Disturbed by Other Signals.—If the intensity of the signals received is great, and violent atmospheric disturbances are present, only the detector described as "insensitive" should be used. If reception is disturbed when receiving by other stations' signals, the coupling should be made as loose as possible, and, if possible, the disturbing station should be cut out by exact tuning to the station to be received by means of the condenser. In this case it will generally be necessary to use the more sensitive detector supplied, as with loose coupling the intensity is very much reduced. In the case of disturbances through violent atmospheric discharges the same procedure should be followed.

CHAPTER XV.

THE PROPAGATION OF ELECTROMAGNETIC WAVES.

IN practical wireless telegraphy various phenomena are encountered during transmission, whereby, with a given aerial energy output, it is impossible to obtain a normal range, or occasionally, and usually unexpectedly, a very much greater range than usual is obtained.

Very great attention, both practical and theoretical, has in the past been devoted to the explanation of these anomalies but without any *very definite* result.

To the practical telegraphist these anomalies, occurring external to his station, are beyond his control. To the wireless engineer these effects are somewhat more important, but, since the situation of a wireless station is chosen on economical rather than technical grounds, questions of geographical nature of range, etc., are usually equally beyond his control, and their importance is hardly any greater in actual practice. The only method of overcoming difficulties encountered (excepting those due to atmospherics which are largely removed by use of the Telefunken or Quenched-Spark musical note) is by increase of power.

In the past it has become the custom of most writers on wireless telegraphy to devote considerable space to anomalies of wireless propagations, and many highly mathematical works have been written, mostly based upon the purely Hertzian oscillator, rather than the earthed transmitter found in practice. In this connection Zenneck has devoted considerable theoretical treatment, and his two standard works should be referred to by those interested in such discussions.

In a book dealing chiefly with wireless apparatus actually used in practice, the author considers it only necessary to devote a brief space to the various phenomena.

He will therefore restrict himself largely to an enumeration of the most important phenomenon. As a convenient means of associating mentally the various phenomena, the author begs to

give an extension of the usual hydrostatic analogy to be found in most modern books on Electricity and Magnetism, not as an actual explanation but as a convenient means of associating and realising the actual effects. It must, however, be borne in mind that this is intended as an analogy only, to aid in visualising the phenomena, and does not aim at being an accurate physical presentation.

Possibly the devotion of further attention, impossible upon the author's part, might lead to an actual explanation on these lines. Even in this case the difficulties experienced would still remain beyond the telegraphist's control.

Actual Phenomena of Electromagnetic Wave Propagation.—If two conductors are fixed to the secondary terminals of an induction coil, and the coil is excited, each conductor will be charged either positively or negatively until a spark passes. If the spark-gap is opened sufficiently to prevent sparking this arrangement will acquire quite an appreciable electrical charge, especially if metallic balls, or better plates (as used in Hertz's original experiments), are fixed to the ends of the conductors. The arrangement therefore acts as a condenser, the air between the conductors acting as a dielectric.

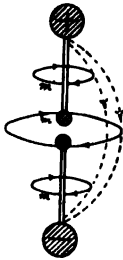


FIG. 217.

Electrical theory formulates the existence of an electrostatic field of force passing through the dielectric between the two conductive plates of a condenser. Furthermore, this field is due to a condition of strain through the ether between positive and negative charges upon the respective condenser plates. This field of strain is considered as being divided up into Faraday tubes, i.e. for each unit of charge upon unit area (the square centimetre) of a charged conductor, an equal number of Faraday tubes of strain arise. The total number of such tubes per square centimetre is usually represented by the symbol D . The number of tubes divided by 4π is the induction N , and should the dielectric capacity be unity the induction per square centimetre is numerically equal to the field of force.

Regarding electrostatic phenomena as due to stresses in the intervening medium between electrical charges, Maxwell showed that each tube exerts a tension $\frac{2\pi D^2}{K}$ upon a charged conductor and also exerts a lateral pressure $\frac{2\pi D^2}{K}$ upon neighbouring tubes.

Sir J. J. Thomson has shown that a magnetic field may be interpreted in terms of the motion of these Faraday tubes, such

motion of the tubes constituting a so-called electrical current along a conductor.

It can be shown¹ that if these Faraday tubes have a velocity V and have an angle θ with their direction of motion they are associated with an amount of energy represented by

$$2\pi\mu D^2 V^2 \sin^2 \theta, \text{ where } \mu = \text{magnetic permeability.}$$

By analogy with the term $\frac{1}{2}mV^2$ for kinetic energy we can consider these tubes as having a "mass" $4\pi\mu D^2$ when moving at right angles to their length. The "mass" will vary proportionally to $\sin^2 \theta$ being nil when moving in the direction of their length, to a maximum of $4\pi\mu D^2$ when moving at right angles to their length. When moving perpendicularly to their length, i.e. the more the tubes are inclined to their direction of their motion the greater is the "mass" value, and consequently the greater is the energy involved in causing such motion.

Each of these hypothetical Faraday tubes of strain is associated with a definite amount of energy which is concerned in the production of an attraction or repulsion between unlike or like charges. We may therefore in many respects picture them as analogous to an elastic cord joining two parallel bodies. With such an elastic cord it is well known that the energy of extension is proportional to the degree of extension, and can be expressed as $\frac{1}{2}$ (stress \times strain). Similarly for electrostatic tubes the energy per unit volume can be expressed as $\frac{1}{2}ED$ where E is of the nature of a stress and D is the corresponding strain.

Similar to the case of an elastic cord which sets in a straight line between its two fixed ends giving minimum length and potential energy, so an electrostatic tube normally tends to have a straight course. If distorted for any reason, such as by the presence of other electrostatic tubes, it assumes a curved form, and the extension so caused represents an increase in energy derived from external sources.

The more the tube deviates from a straight line the greater is its length and corresponding energy, and we can legitimately say that the more the tube becomes curved the greater is its intrinsic energy, obtained by the performance of work external to the tube.

As a further mechanical conception we may consider a soap film which also always sets so that its surface tension energy is a minimum, which is the case when it is either spherical or it passes directly from one solid to another upon which it

¹ Starling's "Electricity and Magnetism," p. 424.

is blown. If external energy is applied in the form of air pressure, the film deviates from a straight line and becomes curved until the surface tension energy is equal to the energy applied. For such films a relation may be obtained which shows that the pressure varies inversely as the radius of curvature, i.e. the greater the energy applied the greater is the curvature.

The production of electromagnetic radiations by the discharge of a condenser arrangement, such as an Hertzian oscillator, is usually described as follows:—

When the potential is great enough to cause sufficient ionisation of the spark-gap, this becomes conductive and a spark passes.

The passage of the current along the total conductive path formed by rods and spark-gap involves the movement of electrostatic Faraday tubes. If the resistance is great, their motion is relatively slow, energy is dissipated as heat, and the discharge is aperiodic.

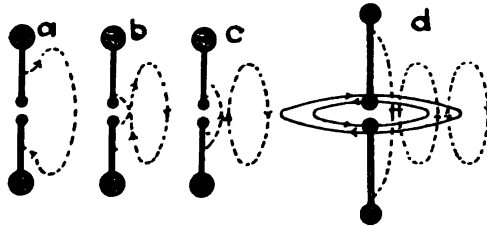


FIG. 218.

If the resistance is, however, below certain limits as defined in Chapter II., a new state of affairs arises.

The electrostatic tubes which tend to collapse, as shown in Fig. 218 *a*, have such rapid motion that they take the form of Fig. 218 *b*, resulting in the reversal of sign of the charges and a folding of the electrostatic tube.¹

Since the tubes tend to repel each other, an unstable condition arises which results in the fracture and breaking free of a portion of the tube. Afterwards, since the electrical sign is different at the ends of the free portion, an attraction occurs, resulting in the formation of a free electrostatic tube ring as in Fig. 218 *c*.

Subsequent reversal of the electrical charges on the condenser results in a series of these rings being disengaged for each spark. Being alternately in opposite direction they repel each other,

¹ It is not academically correct to call this electric field electrostatic when in motion, but for convenience this term is retained.

so that following rings cause the outward displacement of rings as in Fig. 218 *d*.

The motion of these rings involves, as already mentioned, the establishment of a magnetic field which is opposite in sign for alternate rings, and is in Fig. 218 *d* represented by the horizontal whole line rings.

This is the type of radiation first used by Hertz. Popoff's earthed aerial is very analogous. With this the circular electrostatic tube sheets are not entirely free of any conductor, but are completed through the earth which acts as a conductor and the radiation may be represented as Fig. 219.

Since the induction of the soil is much greater than that of air, the tubes of force are concentrated near the surface. According

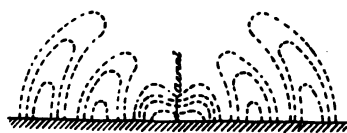


FIG. 219.

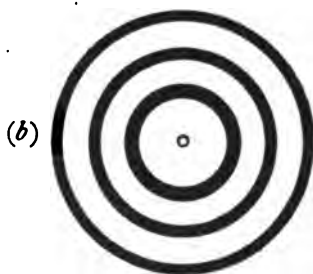
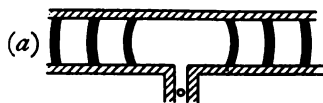


FIG. 220.

to the nature of the land, they penetrate to a smaller or greater depth, negligible in comparison to the height of the free portion.

The free portion of the electrostatic tube, owing to a different velocity of propagation in air and earth, assumes the curved form shown. This curving continues until the tubes reach the upper conducting layer of the atmosphere (Heaviside layer) when the problem becomes similar to that of a condenser, one plate of which is formed by the Heaviside layer and the other by the earth, the electrostatic tubes ending on each conducting plate.

Analogy to Electromagnetic Wave Propagation.—In order to mentally picture the actual phenomena occurring in wireless transmission the present author was led to extend the electrical and hydrostatic analogy to be found in most modern books on Electricity and Magnetism.

This we can do if we imagine Fig. 220 two flat sheets (say of

glass) with an orifice O, into which alternate puffs of water and air can be driven (see Fig. 220 *a*), it being supposed that conditions are such that no collapse of the water between the plates can occur. After a number of puffs we should have a condition in plan as Fig. 220 *b*.

As in the electrical case each water ring would be subjected to two forces due to surface tension, one resisting any internal pressure tending to cause curvature in the vertical plane and one tending to resist any increase of curvature in a horizontal plane.

For such a water ring in the statical case it can be shown that the internal pressure P equals $T \left(\frac{1}{r_1} + \frac{1}{r_2} \right)$ where r_1 and r_2 are the respective radii of the water rings in the planes already mentioned. Since curvature is defined as the reciprocal of the radius, as in the electrical case, we see that the pressure required to maintain equilibrium is proportional to the curvature, i.e. the more the water ring is bent in either direction the greater must be the air pressure to maintain equilibrium.

For a number of rings, the same effect must hold since the total pressure merely involves a summation. For the dynamical case the problem becomes more involved, but, since the air pressure must first overcome the surface tension before movement outwards can occur, the pressure will still be proportional to the curvature.

We may picture a wireless transmitter as the source of energy causing outward displacement of Faraday tubes of induction in much the same way as the energy of our source of air pressure causes outward displacement of water rings. In both cases the amount of energy involved will be greater the more the Faraday tubes or the water rings are bent.

We will apply the view that *propagation is rendered more difficult proportionally to the curvature of the electrostatic induction tubes* in order to attempt to explain wireless phenomena after first enumerating the most important of them.

Wireless Radiation Phenomena.—The extended use of wireless transmitters for signalling purposes has led to the recognition of various effects, the chief of which are the following:—

1. With a given transmitting power, the radiations may be detected to a greater distance the higher the aerial used.
2. Certain forms of aerial will propagate more favourably in some directions than in other directions. For example an aerial having the form of an inverted L aerial will, at least over short

ranges, propagate radiations more favourably in the direction of the foot of the L than in the reverse direction.

3. Transmission is easier over sea than over land, the range being still further decreased if the land is mountainous, thickly wooded, or desert land.

4. The presence of mountains or high land between two stations hinders propagation whilst a river aids propagation.

5. The night range for a given transmitter and aerial is roughly double that of the day range, or even more if the range is, by day, subjected to brilliant sunshine. The period of the year has also a lesser effect upon transmission (doubtless due to the relative intensity of the sunlight and consequent ionisation of the atmosphere).

6. In long-distance work, great difficulty is experienced at the periods of dawn and sunset. Whereas during other periods both by day and night transmission may be relatively easy, at dawn and sunset it may often be quite impossible to maintain communication. Less frequently at these periods very long freak ranges may be obtained.

7. Directive wireless work shows similar great freak positions at dawn and sunset when positions of known stations are observed.

8. Transmission over tropical forests is exceedingly difficult, and is often entirely impossible over very short distances during the daytime even by use of transmitters having many times the range over non-tropical land. Increase in wavelength tends to more favourable transmission in this case but does not entirely remove the difficulty.

9. For a given transmitter, increase in wavelength, i.e. decrease in oscillation frequency, permits a longer range to be obtained.

10. The power required for any range is not directly proportional, i.e. if the transmitted energy is doubled, the range, whilst increased, is not similarly doubled.

11. Longer ranges can generally be obtained in directions parallel to lines of longitude than in directions parallel to lines of latitude.

12. With a given aerial power greater distances can be obtained with continuous (undamped) than with damped oscillations.

1. Effects of Aerial Height (Fig. 221).—Let us imagine two aerial heights represented by AB and AC in Fig. 221. During transmission from either of these aerials electrostatic induction

tubes will be given off, as shown, or more correctly, an electrostatic circular sheet having the aerial as centre. These sheets will, by the repulsion of sheets later formed, travel outwards with a sectional form as shown. The difference of velocity of propagation in air and earth and their inertia will cause them to assume a vertically curved form, and this will continue until they reach the upper conducting layer of the atmosphere, after which we have a similar state of electrostatic strain as between the plates of a normal condenser, one plate of which is the earth itself and the other the upper conducting layer.

Whilst the relative heights of our aerials in comparison to the distance apart of our two conductors are shown greatly exaggerated, the important factor in determining how quickly the tubes reach the upper conducting layer will be their relative height at the commencement of emission. The time (and therefore distance) for them to do this will be greater in the case of the smaller than the higher aerial.

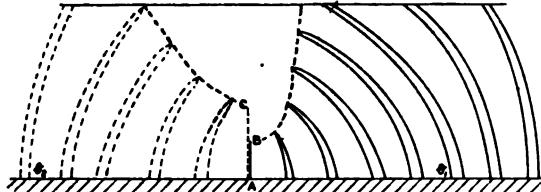


FIG. 221.—Effect of increase of aerial height.

Since the inertia effect is acting during these times it follows that the whole line radiations from the aerial AB will be subjected to bending longer than the dotted radiations from aerial AC. Hence when the former reach the upper conducting layer they will be much more curved vertically than the latter.

Since the tubes have, as already mentioned, an apparent "mass" proportional to their bending, the "mass" of the whole line tubes will be greater than the "mass" of the dotted line tubes.

To give them the requisite velocity in order that they may travel over a given distance, more energy will be involved with those from the smaller aerial than with those from the higher aerial, or, in other words, with a given available energy, the radiation will be easier and therefore cover a longer distance from the higher aerial.

In our hydrodynamical analogy, our water rings will be more curved in the vertical plane, greater surface tension energy is in-

involved and must be overcome before the water-ring can be forced outwards. The energy involved is proportional to the cosine of the angle of contact of water and glass. This angle would be represented in our diagram by the angles θ_1 and θ_2 . Since $\theta_1 > \theta_2$ with due regard to sign, the former angle will have a greater cosine value than the latter. Hence water rings represented by the dotted lines will require a less internal pressure for equilibrium than the whole lines.

The energy involved in producing this pressure and in their movement outwards will similarly be smallest in those shown by dotted lines.

2. Action of Directive L Aerial.—This is analogous to the preceding case. The radiation from such an aerial is usually accepted to be as in Fig. 222. It will be seen that the wave front in direction A is much less curved than in direction B, i.e. the effective aerial height in direction B is b and in direction A is $a + b$. So it is equivalent to having a much higher aerial to radiate in

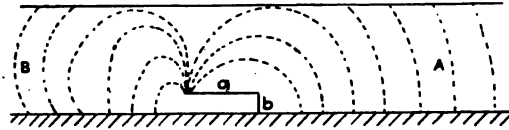


FIG. 222.

the latter direction. Hence the wave front being less curved, propagation will be most favourable in direction A.

3. Increase of Range over Sea as Compared to Land.—It would appear that the greatly increased range over sea may be explained by the fact that sea-water is nearly a perfect electrolyte or liquid conductor. Earth is not nearly so good an electrical conductor, and when extremely dry may be a very bad conductor.

It is well known that an electrostatic induction tube ends at an angle of 90° upon a perfect conductor, whilst with an imperfect conductor (such as earth) it enters obliquely.

With such an imperfect conductor the motion of the ends of the electrostatic tubes along it involves the expenditure of energy, and they are inclined to it at an angle. The resistance of the conductor has the effect of retarding the ends of the tube, and they are dragged along by the rest of the tube in opposition to this retardation.

This effect, shown by a diagram on page 419 of Starling's "Electricity and Magnetism," results in a general bending of the tube.

Since the more the tube is bent the more the "mass" increases, it is evident that over a good conductor, as sea-water their "mass" will be less than over bad conducting land. So, for any given energy of transmission, other things being equal, transmission will be much better over sea.

According to the relative conductivity of the land so will the range vary overland, being best over humid land and least over non-conducting rock or desert land, as occurs in practice.

We might extend our surface tension analogy to this case by mentally replacing the lower glass plate by ground glass or some other rougher medium for which the surface tension with water is much greater. The curvature of the water rings would be also much greater and hence greater air pressure be required for motion. In actual practice it would be most likely the water rings would break since they would assume a very curved form, eventually becoming so attenuated that the surface tension

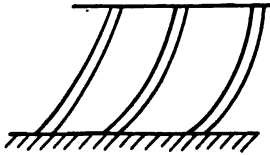


FIG. 223.

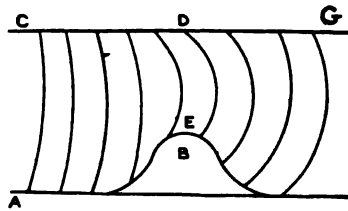


FIG. 224.—Effect of mountain.

would be enormous, and the surface energy would cause drop formation.

We can consider an analogous case for the electrostatic tubes in which they are dragged along as Fig. 223 and become so attenuated that their impinging upon a conductor would involve very little energy, i.e. they would fail to be detected.

The relative ease with which wireless communication can be established along a river, as compared to over land only, may be considered as similar to the case of sea-water. The emitted electrostatic radiations largely take the path of least resistance (i.e. of least energy dissipation) along the river rather than over land. In other words least retardation and bending occurs along the path of the river so that as great a mutual repulsion between similar tubes does not occur as on land. The velocity of the tubes and hence transfer of energy is greatest along the river.

4. Effect of Mountains.—Mountains as a general rule hinder

efficient wireless transmission. Stations are preferably not separated by mountainous or high land if another site is possible.

The effect is much worse if the mountain is not roughly in the mid-point of the range, or either station is in the "electrical shadow" of a mountain.

The effect may be considered as due to the bending of the electrostatic tubes as in Fig. 224.

Let CDG be the Heaviside layer, B a mountain.

Neglecting earth resistance losses in unit time equal transfer of energy must occur across CA and DE, and at DE the tubes must be much more crowded together. Therefore their mutual repulsions must be greater, and they must be more curved at DE as indicated in the figure. The energy involved in their movement against their mutual repulsion must so be greatest at this point.

After passing DE they may or may not regain their original curvature according to conditions.

Whilst the tubes would take this form in section, since in the plane vertical to the paper the mountain is not infinite, propagation will be easiest around the mountain. The electrostatic tubes will tend to take a path of least resistance around the mountain. Any receiving station lying in the electrical shadow of the station will so receive little energy.

For a similar reason propagation is much more easy along a valley between mountain ranges. Rather than cross the ranges, the tubes tend to pass along the path of least resistance, requiring less curvature and energy expenditure along the valley.

5. Day and Night Effects.—As already mentioned the range obtained by a wireless station is always much greater by night than by day.

As far as the author is aware no explanation other than ionisation has been offered regarding this effect.

It is well established that above the non-conducting atmosphere is a conducting layer ionised by the sun's rays, often called the Heaviside layer. This is known to vary in height, being lower by day and higher by night. For a transmitter evolving a definite amount of energy, it is evident the electrostatic tube energy must be constant both by day and night. In a more confined space as in the day position, there must be a greater value of energy per unit volume than in the night position. So the tubes are more crowded together and their mutual repulsions are greater (Fig. 225). For their propagation against these repulsions more energy is needed.

This may possibly be the explanation of the increased night range when the Heaviside layer is highest.

Our surface tension analogy can be made to illustrate this case if we drop the upper glass plate, when the water-rings become more curved in the vertical plane and require greater air-pressure to force them outwards.

Dawn and Sunset Effects.—As a general rule wireless transmission is best by night, worse by day, and may be totally impossible during dawn or sunset.

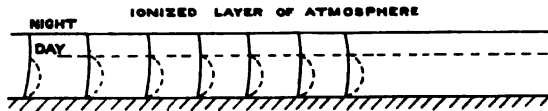


FIG. 225.

Regarding the earth as a sphere illuminated by a source of light S (the Sun) there will be a dark portion of the atmosphere at D and a light portion at L. We can legitimately neglect the effect of diffraction since the effect of this is secondary, i.e. instead of the light and dark boundary being sharply defined as shown, it will be blurred.

Since sunlight causes ionisation of the atmosphere and therefore variation of its electrical properties the velocity of an electromagnetic wave will vary in the light and dark portions of the atmosphere.

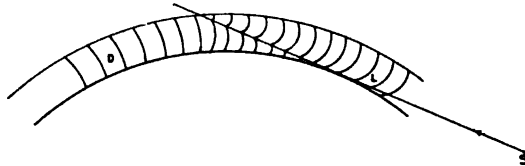


FIG. 226.—Sunset and dawn effect.

Hence we have a refraction of electrostatic radiations exactly analogous to the refraction of much smaller electromagnetic radiations commonly called light.

The effect of passage from the dark to light portions of the atmosphere across the boundary will be to cause the electrostatic tubes to become bent (in an extreme case they may be so bent that they leave one of the conducting surfaces). Their further propagation with the energy available may be impossible, or in any case very difficult, owing to their curvature being increased.

The effect will in general be the same whether they pass from the light to dark zone or vice versa.

One case must be, however, recognised. Previously curved tubes may undergo refraction to an extent which instead of causing further curvature, causes them to become less curved.

They would then be capable of easier propagation and longer ranges than normal become possible. The author whilst responsible for the operation of a large number of ship installations scattered over the World has frequently known such abnormally long ranges at dawn and sunset which would tend to bear out the curvature view adopted here.

Directional Work at Dawn and Sunset.—Round has stated that in direction-finding work, accuracy is impossible during dawn and sunset, Eckersley having in Egypt obtained readings on known stations as much as 90° in error.

It is obvious that the effect just dealt with would not only render propagation more difficult, but there would be the tendency for the electrostatic tubes to be forced along paths of lesser resistance, after the manner described on the previous page. For example, radiations between two stations from N. to S. crossing a sunset border, would to a more or less degree be forced in the E. to W. direction, where they would escape refraction across the sunset light and dark boundary. Errors introduced owing to disturbance of the wave front, would (and always will) render accurate direction-finding work impossible during dawn and sunset, as is the case.

Further errors in directional work are due to the receiving station lying in the shadow of a mountain and changes in transmitting aerial form. The possible causes of these effects have already been mentioned.

With directional observations on aircraft, Round states that signals vary with the direction of flight of the air vessel, and accurate readings can only be obtained when the vessel is "end-on" to the direction-finding station. The signals change from a maximum to a minimum when the station completely reverses its direction.

The intensity of readings also vary with the vessel's height, which is evident when we remember the direction of the wave front to the receiving aerial from the source upon the aeroplane will vary in direction with its height and position, a state of affairs illustrated by Round by Fig. 227, in which the direction of the wave front is not normal to the receiving frame.

The aeroplane aerial itself varying in direction with its speed

also introduces a further error not eliminated in the end-on position.

Effect of Forests.—Particularly in South America great difficulty of transmission over the tropical forests occurs by day, and communication is often entirely impossible.

The day and night effect already mentioned may be one cause of this, but another effect must be mentioned.

Sir Oliver Lodge¹ and others have shown that, particularly

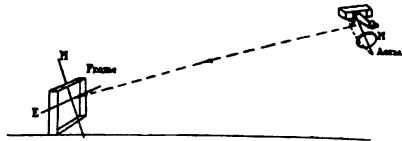


FIG. 227.

in sunlight, plants produce an electrified or ionised atmosphere above them, this effect being continued until a sudden reversal occurs producing a lightning storm (particularly frequently) in the tropics.

This electrified atmosphere near the earth would not only have the effect of somewhat decreasing the distance between the true earth and upper conducting layers, but also give rise to another effect.

Consider a transmitting aerial at A (Fig. 228) and a receiving

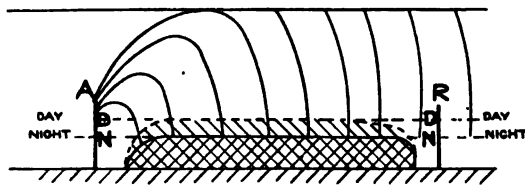


FIG. 228.

aerial at R and the limits of electrification due to the vegetation to be N by night and D by day.

Below these limits the atmosphere would be conductive and correspond to the presence of the actual earth.

The effective heights of the aerials will therefore be AD and RD by day and AN and RN by night, so the problem reduces to the case of a decrease in aerial height.

Since the height of aerials will not be relatively very much

¹ Kelvin Lecture, Inst. of Elect. Eng., 1912.

greater than the forest height and therefore of the electrified air bank, the effect will be very considerable and most important by day during brilliant sunlight.

Under certain conditions the electrified bank of air may completely envelop one or both of the aerials. Transmission will then be totally impossible. Vessels which pass up the Amazon River in the midst of virgin forests often find that by day it is impossible to receive signals from a powerful relatively near station.

In such situations natural electrical discharges ("atmospherics" or X's) also render reading of signals difficult. Such difficulties are largely overcome by use of the Quenched-Spark musical note and long wavelengths.

This problem may be regarded in another manner. Colonel G. O. Squier of the U.S. Army found that a living tree could be utilised as an aerial (i.e. a vertical conductor), by making suitable connections at the root and above. In actual working, suitable trees must similarly act as receiving aerials and intercept electromagnetic radiations. Hence an aerial erected amidst trees would be shielded by the conducting trees except for that part, as we have already mentioned, which projects above the trees.

9. Effect of Increase of Wavelength.—Practice has established the fact that communication can be maintained best by use of long rather than short wavelengths.

Two effects may be considered in this relation. When erecting a transmitting station for long wavelength working, as large an aerial as possible is built, which will tend to have a long natural period of oscillation, comparable to that of the desired wavelength, in order to prevent a dissipation of energy due to artificial loading of the aerial with inductance.

This will generally result in the use of higher aerials and so better radiation will be obtained.

The second effect may be best understood from Fig. 229.

It is evident that a growing electrostatic sheet upon an aerial arrangement has not only to draw energy from the transmitter prime mover for its own outward displacement but also to draw sufficient energy to allow it by its own repulsion to push preceding sheets still further outward. The effect is a summative one, i.e. the larger the number of preceding sheets the greater must be the energy necessary to throw off new sheets.

To refer now to Fig. 229, points of maximum electrostatic stress have been indicated half a wavelength apart by wave fronts. For equal ranges with small wavelengths the number of

such wave fronts are greater than for long wavelengths. Hence to cause equal transfer of energy between two points, greater energy will be necessary to propagate the increased number of wave fronts with the smaller wavelength.

To complete this view we must mention that whilst the energy received at a wireless station equals the sum of the energy of the electrostatic tubes per unit time, with a longer wavelength fewer wave fronts may be received, but each wave front involves a greater energy value if the same energy is being radiated from the transmitting station.

Our surface tension analogy serves to illustrate this effect if we imagine a different frequency of air puffs per unit time and therefore a different number of water-rings between the same two points in each case.

10. **Falling off of Range with Increase of Power.**—The author's explanation of this effect is pure speculation, but whilst

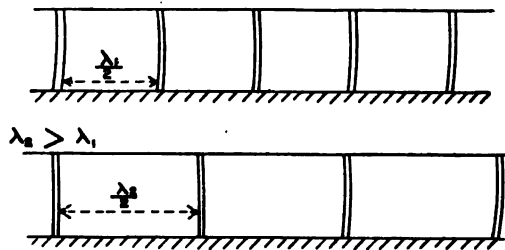


FIG. 229.

formulae have been proposed (especially by Austen) for relation between power and range these have all been largely based upon empirical results of intensity measurements at different points rather than upon actual interpretation of the physical phenomenon.

Let us imagine in our water-ring analogy that we have a large number of water-rings. As we pass from our centre of emission, owing to the inertia of distant tubes some time must elapse before, with a fresh air puff, the outermost rings receive a fresh impulse outwards. Moreover, since energy would be expended in causing motion of the more internal rings, the energy available to move each ring would fall off as we pass outwards.

On section we should therefore theoretically get a picture as Fig. 230, in which as we pass outwards the rings become rapidly crowded together. Since for unit horizontal length the energy involved in displacement is proportional to the number of rings the

energy of outward motion across AB will be less than that across BC, and this less than that across CD, etc., the increase of energy rapidly becomes very great the more we pass outwards, and increasing at an exponential rate.

In practice with water the number of rings which could be actually obtained would be very few, since the energy of surface tension would very rapidly increase. Rather than pass outwards, the surface tension energy would tend to be distributed over a great area and the rings would so break up into drops.

We may imagine electrostatic tubes of wireless transmission undergoing the same kind of effect so that (as is actually the case) increase of energy is not directly proportional with range but increases very rapidly. In using this analogy we must, however, bear in mind that in our model we have air between our water-rings which is very compressible, and energy is very largely taken up in compression of the gas, so at the periphery the rings become very crowded together. In the electrical case we have not

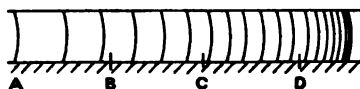


FIG. 230.

a material compressible substance as air, but the ether which Lord Kelvin has shown must be as incompressible as steel, whilst its density is infinitesimal. The crowding effect would therefore be very great in our model but very much smaller in wireless propagation.

The correctness of this view of increase of energy could be actually determined by measurements to ascertain if *change of wavelength occurs with distance from the source*, carried out over very long distances.¹

¹ The author is well aware that in physics the wavelengths corresponding to certain spectral lines is so constant that it has been proposed to base all absolute measurements of length upon such wavelengths.

It must, however, be remembered that whilst such extremely small wavelengths appear to us to be extremely constant, if our refinements of measurement were sufficiently great, variations might be found to occur.

It is therefore not strictly accurate to assume exactly the same properties for light electromagnetic waves as for wireless electromagnetic waves when the former are of the order 10^{-4} millimetres, and the latter, at the other end of the scale, are of the order of 20 miles or more.

As an example of the fallacy of such deductions we may instance the case of velocity of chemical reaction for two chemical substances which in the gross solid state may react very slowly, whereas the same two bodies in a very finely divided state may have such a great velocity of reaction as to produce an explosive reaction. To take a physical case, there was until recent years no more fundamental conception of constancy than that of mass, yet Einstein has disputed such a conception, and his views have been borne out by experiment,

In connection with the decrease of emitted power with distance from the source, it should be noted that although many authors state that, as with light, this falls off inversely as the square of the distance, this is not strictly correct. A tuned receiving aerial forms an easy path for electrostatic and electromagnetic energy to be changed to heat energy in the conducting aerial. The receiving aerial therefore destroys the electrical energy of the wave front whose path it cuts. Moreover, there must be a convergence of energy from the neighbouring space, since further electrostatic tubes will tend to converge upon the aerial seeking the easiest path for its conversion to heat energy. So when one part of the wave front is destroyed neighbouring tubes are repulsed by their neighbours to the more free space where electrical energy is being changed to heat energy. The received energy must therefore be greater than that determined by any inverse square law and aerial dimensions.

II. Difference of Range with Geographical Position.—

Marconi in 1911 drew attention to the fact that signals could be more easily transmitted in a north-south than an east-west direction, as the result of experiments in the Atlantic.

Those familiar with operator's logs will agree that in the Pacific Ocean most extraordinary ranges can sometimes be obtained for no apparent reason.

Stanley states that the earth's magnetic field has no effect on wireless propagation. If, however, we refer to a magnetic map of the World,¹ it is very noticeable that both the Atlantic Ocean and the Pacific Ocean are remarkable in so far that in the former the isogon lines pass north to south and in the latter east to west.

It is by no means conclusive, but not unlikely, that the earth's field has some effect upon transmission. Simultaneous readings of signal strength from a constant source and variation of the earth's magnetic field might aid the solution of this question.

If we regard motion forward of a single electrostatic sheet, this by its motion is accompanied with the growth of a magnetic field of strain.

If the established field is in the direction of the earth's field its growth will be easy and vice versa, i.e. energy transfer between two points will be easier, since energy consumption for establishment of the magnetic field is smaller in one direction.

¹ See Starling's "Electricity and Magnetism," p. 35.

The effect of compounding the longitudinal earth's magnetic field with the circular wireless magnetic field is to cause the latter to become elliptical, and the electrostatic wave front will have a similar form but in the vertical plane.

The curvature of an ellipse (i.e. $\frac{1}{r}$) is greatest in the case of those portions at the extremities of the minor axis and least in the portions at the extremities of the major axis. On our view, that the propagation of electromagnetic effects is directly as the curvature of the Faraday tubes, propagation will be most easy along the directions of the major axis and vice versa.

With our surface tension model this would actually be the case if we imagine our hitherto circular water-ring to become elliptical, and the result of the application of internal air-pressure would be to cause the water-ring to grow in the directions of the major axis until the film became very attenuated and broke.

When we try to apply this view to electromagnetic radiation, however, our analogy, whilst valid, fails since the direction of the electrostatic and accompanying magnetic field is not unidirectional but constantly reversed in direction. So we must suppose that whilst for half a period propagation is best in one direction, for the next half period the earth's field opposes propagation. Unless we adopt such views as of signalling maintained by half cycles, our analogy does not hold. As, however, crystal detectors rectify in only one direction, this view would hold if rectification was occurring at the crystal for those half cycles most favourably propagated.

12. Advantage of Continuous Wave Signals.—Neglecting telephony by continuous waves, which requires very much greater intensity of signals, work of recent years with continuous waves, for Morse signalling by valve generators, has shown that a much greater range with a given aerial output can be obtained by continuous waves than with damped trains of waves due to spark generators.

A possible explanation of this effect is that the atmosphere being always more or less ionised by the sun's rays and otherwise, an electrostatic wave front undergoes attrition owing to its imparting energy to the ions and electrons. Eccles has discussed the change of velocity of ether waves as a result of the atmosphere's ionisation and its effect on the form of the wave front.

A further effect of valve transmitters is that the rapidly oscillating electrical energy has nearly a pure sine form. With other continuous wave generators as machine and arc stations

a pure sine form is never attained, since harmonics and other distorting effects always occur, and undoubtedly this has an equal effect upon the actual form of the electrostatic tubes, besides introducing difficulties purely concerned with beat reception.

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